END-POINT CONTROL OF A MINIATURE FLEXIBLE ARM DRIVEN BY PIEZOELECTRIC BIMOPRPH CELLS

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Abstract

A theoretical and experimental study is presented for the end-point position control of a miniature flexible arm, whose base is under a lateral fluctuation. The arm is driven by piezoelectric bimorph cells cemented on both surfaces of the arm. It is controlled so that the end-point stays precisely at its initial position. It is shown both theoretically and experimentally that the PID control using the tip information as a feedback signal is effective for the end-point positioning of the cantileverarm with a lateral fluctuation at the base.

1. Introduction

The requirements for suppressing the vibration of miniature flexible arms such as the slider suspension in the disk drive unit have created interest in the development of actuators made of piezoelectric materials. It is well known that the piezoelectric actuator produces a large force compared with the volume and responds quickly to the excitation voltage[1].

This paper is a study on the active position control of a miniature flexible arm driven by piezoelectric bimorph cells, whose base is under the influence of the translational fluctuation. The arm is controlled so that the tip stays precisely at its initial position even if the base is disturbed by the fluctuation. The scheme of tip sensing and base bending is introduced to control the arm tip together with the use of PID feedback rule.

2. Formulation of the problem

Figure 1 shows a flexible cantilever of length l with the piezoelectric bimorph cells glued on both surfaces from l_1 to l_2. Two co-ordinate frames are introduced in the system. One is the frame fixed in space, which is shown by (X, Y). The other frame is the one moving with the translation stage, which is denoted by (x, y). In this case, X and x are common while Y and y are related each other through $Y = y + U(t)$. Here, U is the fluctuation of the stage with respect to the frame (X, Y). Denoting the relative displacement of the arm to the translation stage also by y, the equation of motion of the arm is given by

$$\begin{aligned}(\frac{\partial^2}{\partial x^2})[E(x)I(x)(1+c\frac{\partial}{\partial t})\frac{\partial^2 y}{\partial x^2}] + [\rho(x)A(x) + m\delta(x-l)]\frac{\partial^2 y}{\partial t^2} \\ = M_p[\delta'(x-l_1) - \delta'(x-l_2)] - [\rho(x)A(x) + m\delta(x-l)]\frac{d^2U(t)}{dt^2}.\end{aligned} \quad (1)$$

One assumes the solution of eq.(1) in the form

$$y(x,t) = \sum_{n=1}^{N} y_n(t) = \sum_{n=1}^{N} w_n(x) f_n(t), \quad (2)$$

where w_n is the n-th mode function of the arm-cell system. In the following, one studies the problem of controlling the arm so that the tip stays precisely at its initial position even if the

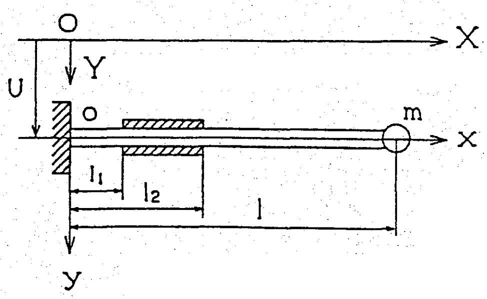

Fig.1 Geometry of problem and coordinates

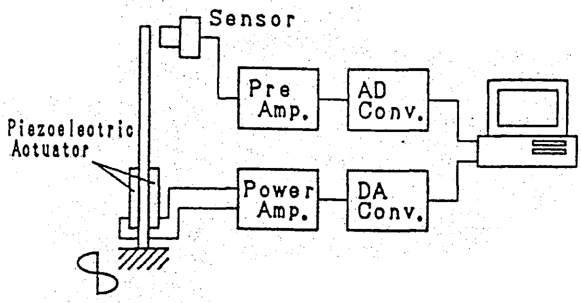

Fig.2 Experimental system

Table1 Physical parameters of bimorph cells and beam

	Arm	Piezo. Cell
Length(m)	157.3×10^{-3}	40.8×10^{-3}
Width(m)	12.2×10^{-3}	12.2×10^{-3}
Thickness(m)	0.3×10^{-3}	0.65×10^{-3}
Mass density(Kg/m^3)	8.67×10^{3}	8.3×10^{3}
Young's modulus(N/m^2)	102.5×10^{9}	58.03×10^{9}
Internal damping coefficient(s)	3.91×10^{-4}	
Tip mass(kg)	12.1×10^{-3}	
l_1(mm)	2.5×10^{-3}	

base is disturbed by the lateral fluctuation $U(t)$. To this end, one introduces a PID control scheme using the tip information as a feedback signal. The sensor's measurement of actual tip position $y(l,t)$ is compared with the desired tip position $y_d(l,t)=0$, and the error (y_d-y) is used, together with the estimated end-point velocity and the integrated error, as a basis for applying control moment to the arm base through the deformation of the piezoelectric cells. The moment M_p applied to the arm from the cells is

$$M_p(t) = -G_p y(l,t) - G_v \dot{y}(l,t) - G_I \int_0^t y(l,\tau)d\tau, \tag{3}$$

where G_p, G_v and G_I are the position, velocity and integral feedback gains respectively.

To solve eq.(1), one introduces the time discrete method with the sampling time τ taken as a parameter. Applying the Galerkin method and the Duhamel integral, one has the solution of eq.(6) as

$$\begin{aligned} y_n(\overline{j+1}\tau) &= \mathrm{e}^{-\mu_n\tau}(\alpha_n \cos p_{d_n}\tau + \beta_n \sin p_{d_n}\tau) \\ &+ \frac{R_n(j\tau)-S_n(j\tau)}{\mu_n^2+p_{d_n}^2}[1-\mathrm{e}^{-\mu_n\tau}(\cos p_{d_n}\tau + \frac{\mu_n}{p_{d_n}}\sin p_{d_n}\tau)], \end{aligned} \tag{4}$$

where $S_n(j\tau)$ is a function of the fluctuation of the stage $U(t)$ and $R_n(j\tau)$ the function of control moment $M_p(t)$.

3. Results and Discussions

Figure 2 shows the experimental setup of the system controller. The displacement of the arm tip was measured by a gap sensor mounted on the translation stage which is driven by a d.c. servomotor and a timing belt. The arm is also placed on the translation stage. Table 1 shows the physical parameters of the arm-cell system on which the experimental results were

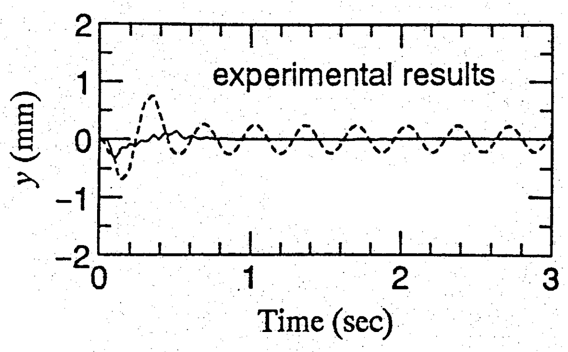

Fig.3 Displacement of arm tip

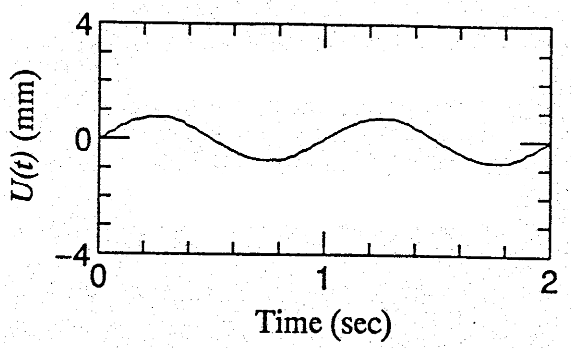

Fig.4 Displacement of arm base

obtained. The theoretical 1st-mode frequency is 3.11Hz, while the experimentally obtained one was 2.97Hz.

Figure 3 shows the experimental results when the stage was translated as

$$U(t) = \begin{cases} 5\sin^2 \omega t, & (0 \le t \le \pi/2\omega) \\ 5 & (\pi/2\omega \le t) \end{cases} . \tag{5}$$

Here, ω has been set to π, which means that the arm base is driven for 0.5 sec as $\sin^2\omega t$, then placed at the position U=5mm. The dashed line in Fig.3 shows the tip response without feedback control, while the solid line the response when the PD feedback control was introduced. It is evident that for the latter case the arm vibration has been suppressed successfully.

One next examines the case when the arm base is subjected to a continuous sinusoidal fluctuation. The translation stage was driven by using the PID feedback scheme so that it tracks the target sine function $U = 2\sin(2\pi t)$ (mm). Experimental results showed that a minute fluctuation appears on the stage during the tracking of pass function(Fig.4). Figure 5 shows the power spectrum of Fig.4. By reading the peak amplitudes from the curve, the motion of the stage is formulated as

$$\begin{aligned} U(t) = \frac{2.0}{1.1} \times 10^{-2}[&1.1 \times 10^2 \sin(2\pi t) + 9.1\sin(2 \times 2\pi t) + 2.6\sin(3 \times 2\pi t) \\ &+ 7.8\sin(4 \times 2\pi t) + 2.0\sin(5 \times 2\pi t) + 1.6\sin(7 \times 2\pi t) + 1.0\sin(9 \times 2\pi t) \\ &+ 1.1\sin(17 \times 2\pi t) + 1.3\sin(18 \times 2\pi t) + 1.4\sin(19 \times 2\pi t)]. \end{aligned} \tag{6}$$

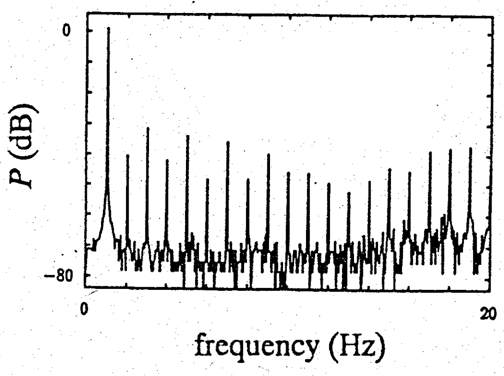

Fig.5 Power spectrum of displacement at the base

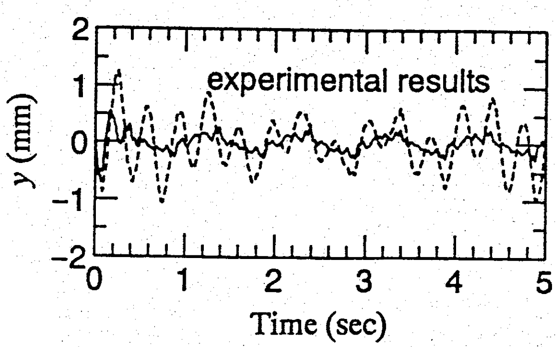

Fig.6 Displacement of arm tip

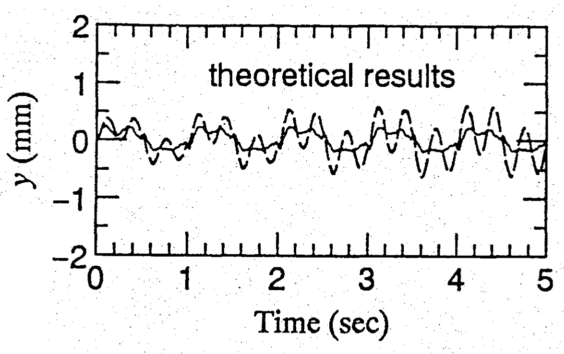

Fig.7 Displacement of arm tip

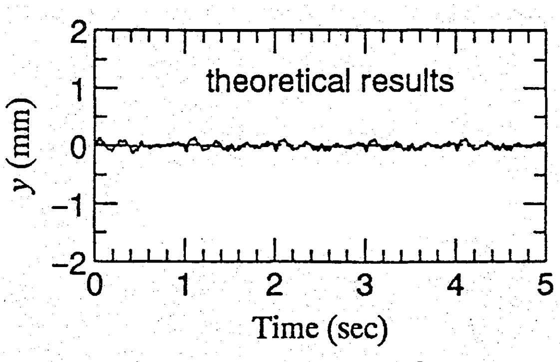

Fig.8 Displacement of arm tip

Figure 6 shows the experimental results when the stage was driven as Fig.4. The corresponding theoretical results are given in Fig.7, where the input to the arm base has been assumed by eq.(6). The theoretical results are in good agreement with the experimental ones. The dashed line in Figs.6 and 7 is the results when the arm is driven from $t=0$ without the feedback control, while the solid line the case when the arm tip was positioned by the PD feedback control. It is again said that mostly the control scheme proposed here is effective for the positioning of the arm, however it does not respond properly to the high-frequency minute fluctuations.

In the experiment, the input voltage to the piezoelectric cells was limited to $\pm$ 50V considering the durability of the cells to the applied voltage. Figure 8 shows the theoretical results when no such limitations were placed on the feedback gains or the control voltage signals. The dashed line in Fig.8 is the case when the input is a pure sinusoid $2\sin(2\pi t)$ (mm), while the solid line the case when it is given by eq.(6). Figures show that the tip holding control cannot be done precisely when the input fluctuation has high-freqency components, even if no limitations were placed on the control voltage to the cells.

It is noted from the above discussions that the positioning of the arm tip can be achieved satisfactorily by using the scheme of tip sensing and base bending provided the fluctuation of arm base is relatively slow compared with the fundamental frequency of the arm, while it is not the case when the disturbance has high-freqency components.

4. Conclusions

Tip sensing and driving at the base by piezoelectric cells is effective to make the arm tip stay at its commanded position if the time variation of the disturbance at the base is relatively slow compared with the fundamental freqency of the arm, while the control is not satisfactory when the disturbance includes high-freqency minute fluctuations.

5. References

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