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エネルギー分析器，選別器には，静電式擬似半球型を用いている．（Fig. 3）

(Fig. 2)

分析器，選別器の分解能は理想的には通過エネルギーと幾何学的条件によって決まる．この実験装置では，調整を行った後，最終的には総合分解能を 100 meV以下にする．

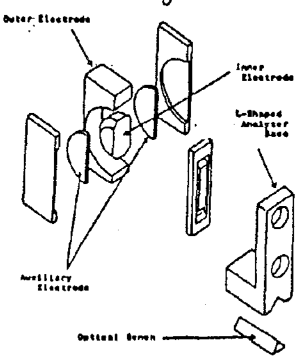

Fig. 3

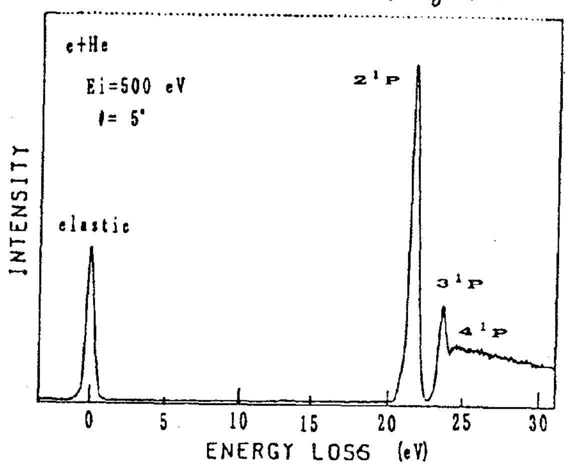

Fig. 4

Fig. 4 に実験装置調整のための予備実験により得られた He原子のエネルギー損失スペクトルを示す．エネルギー選別器，分析器の分解能の向上，電子ビーム強度，検出効率の向上が主な調整の課題である．

実験装置の調整終了後に，我々は Xe-4d 電子の励起過程の研究を行う予定である．光吸収による研究は良く知られているが電子衝突によるものはまだ良く研究されていない．

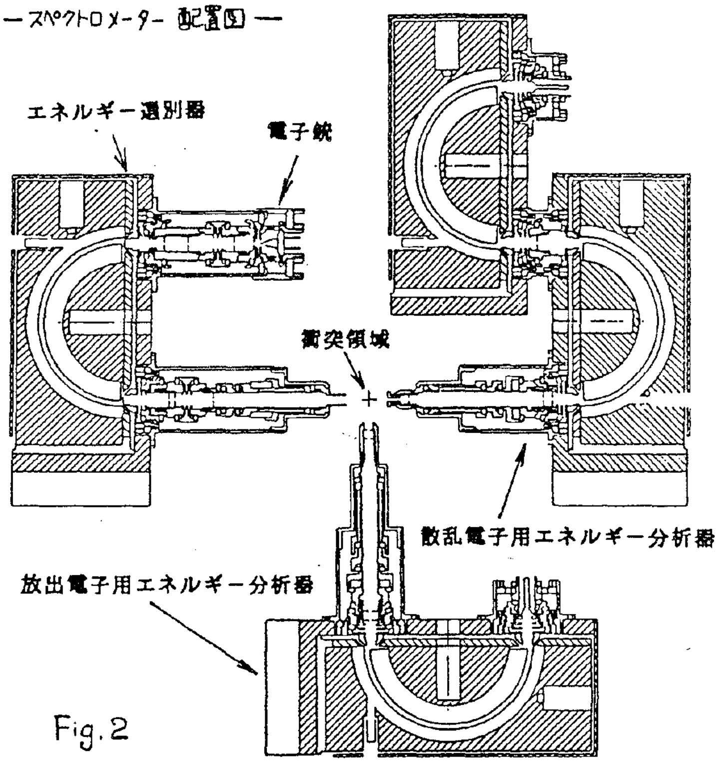

Fig. 2

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2. 圧電素子のパルス駆動方式

杉 山 茂 孝

1. Introduction

Recently, piezoelectric and electrostrictive actuators have become very popular as micro-displacement transducers[1]. These actuators are largely divided into two categories according to the strain used: In one, a rigid displacement is induced unidirectionally by an applied field, and in the other, a resonating strain(i.e. ultrasonic motors) is excited by an AC field. The former is further classified into two types. These are servodisplacement transducers controlled by a feedback system through a position-detection signal and pulse-driven motors in an on/off manner, which are applicable to impact printers and ink jets etc.

So far, piezoelectric devices (not as actuators) have been used mostly in mechanical resonance, and analysis for the resonance has been treated in details in many reports. On the contrary, detailed analysis for pulse-driven motors can not be found in published papers. A significant difference compared to ultrasonic motors with steady resonating displacements is the use of transitional vibrations induced by a pulsed voltage. When a square pulse or a step voltage is applied on a piezoelectric actuator, in general, an overshoot of the induced strain occurs first, then followed by ringing with a period almost equal to a mechanical resonance of the actuator. These overshoot and ringing are detrimental to achieve quick and precise response of the actuator.

To diminish the ringing, Smiley proposed experimentally the use of a pseudo-step field with a rise time corresponding to the resonance period[2], and Kubo et al. indicated the combination of a pair of step voltages[3]. This paper aims to clarify the theoretical background of their ideas. In addition, to support the analysis the experiment has been made by using a bimorph actuator.

2. Analysis using Laplace Transform Operator Method

For mathematical simplicity, we describe here the analysis on a transversely vibrating mode of a rectangular plate sample. The notations of the size and the coordinates are given in Fig.1. Discussion can be easily extended for the other vibration modes.

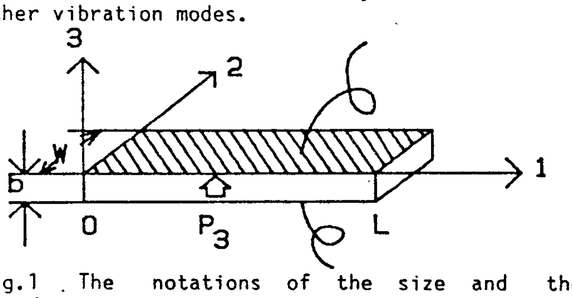


Fig.1 . The notations of the size and the coordinates

As is well known, a kinetic equation for the transverse mode of a piezoelectric actuator is represented as follows:

$$\rho\left(\frac{\partial^2 u}{\partial t^2}\right)=\frac{1}{s_{11}^E}\left[\frac{\partial^2}{\partial x^2}\left(u+\delta\frac{\partial u}{\partial t}\right)\right] \quad (1)$$

where ρ is the density of the actuator ceramics, s_{11}^E is an elastic compliance along 1 axis, u is the displacement in 1-direction and δ is the loss coefficient.

When the loss is equal to zero, the equation is reduced to

$$\rho\frac{\partial^2 u}{\partial t^2}=\frac{1}{s_{11}^E}\frac{\partial^2 u}{\partial x^2}. \quad (2)$$

In addition, we need the following piezoelectric relations to solve the equation.

$$X_i=s_{ij}^E X_j+d_{mi}E_m, \quad (3)$$

$$D_m=d_{mi}X_i+\varepsilon_{mk}^X E_k. \quad (4)$$

The Laplace transform operator method makes it easy to obtain transitional solutions. When we denote Laplace transforms of u(t,x) and E (t) with respect to t as U(s,x) and $\widetilde{E}(s)$, Eq.(2) is transformed as

$$\rho s_{11}^E s^2 U(s,x)=\frac{\partial^2 U(s,x)}{\partial x^2}, \quad (5)$$

where the initial conditions as follows are used:

$$u(t=0,x)=0, \quad (6)$$

$$\partial u(t=0,x)/\partial t=0. \quad (7)$$

Considering the boundary condition at x=0,L

$$X_1=\frac{1}{s_{11}^E}(x_1-d_{31}E_3)=0, \quad (8)$$

the following equation is derived from Eq.(5)

$$U(s,x{=}L)=d_{31}\widetilde{E}\frac{v}{s}\frac{1-e^{-sL/v}}{1+e^{-sL/v}}=d_{31}\widetilde{E}\frac{v}{s}\tanh\left(\frac{sL}{2v}\right), \quad (9)$$

where v(sound velocity of the ceramics) is introduced by the relation,

$$1/v^2=\rho s_{11}^E. \quad (10)$$

The displacement ΔL of the sample is 2u(t,x=L). When δ is finite, s is replaced by $s/(1+\delta s)^{1/2}$ in the Eq.(9).

When a pseudo-step with a rise time of rL/v (r:parameter) is used, the Laplace transform of field E(t), $\widetilde{E}(s)$, is represented by

$$\widetilde{E}(s)=E_0\frac{v}{rLs^2}\left(1-e^{-rLs/v}\right), \quad (11)$$

Then, U and ΔL are calculated as

$$U(s,L)=d_{31}E_0\frac{v^2}{rLs^3}\tanh\left(\frac{sL}{2v}\right)\left(1-e^{-rLs/v}\right) \quad (12)$$

and

$$\Delta L(t)=2u(t,L)=2L^{-1}U(s,L). \quad (13)$$

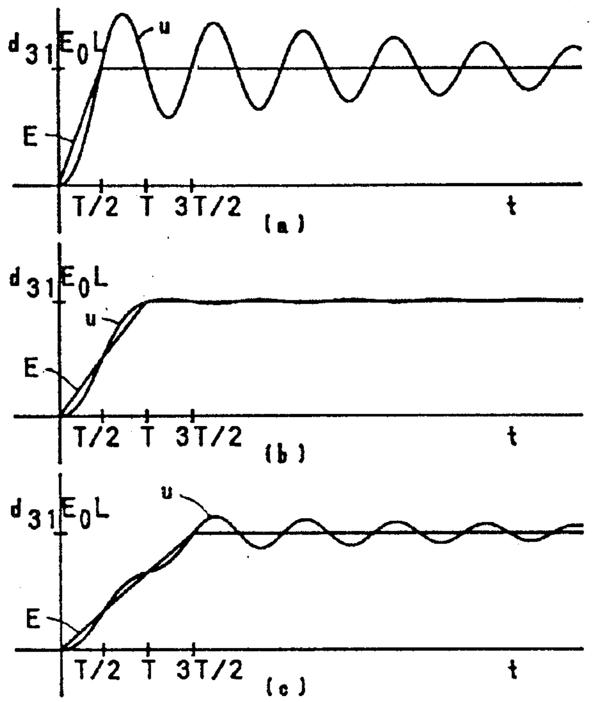
Using a general Laplace relation,

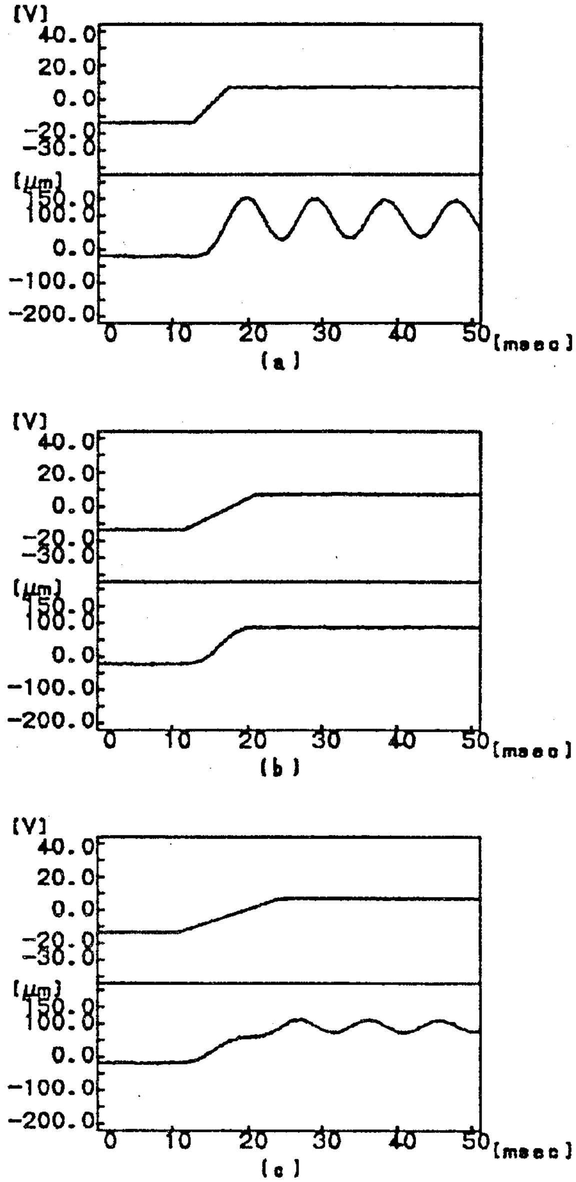
$$L^{-1}\{F(s)e^{-ks}\}=f(t-k), \quad (14)$$

the displacement ΔL is calculated. Figure 2 shows the result calculated for loss parameter δ=0.02 by replacing s by $s/(1+\delta s)^{1/2}$.

Fig.2. Theoretical simulation of response of induced strain to an applied step field for a rise time in the case of a finite loss of δ=0.02. (a) and (c) are half odd times of and (b) equal to the resonance period T.

As a result of Fig.2, an overshoot and ringings do not occur when a pseudo-step field is applied with the rise time of integer times of the resonance period. On the other hand, in case of half-odd times, the largest ringing is produced as shown in Fig.2 (a) and (c).





3. Experiments

Experiments have been performed using a bimorph actuator made of a hard type piezoelectric material with a mechanical quality factor Q=1000. The block diagram of the experimental arrangement is shown in Fig.3. The voltage was supplied with a pulse generator (NF CIRCUIT DESIGN BLOCK CO, LTD.;FG-163) and a voltage amplifier (NF CIRCUIT DESIGN BLOCK CO, LTD.;4005 HIGH SPEED POWER AMPLIFIER). The induced displacement was monitored using an eddy current-type sensor (KAMAN Measuring System; KD-2300,0.5SU) installed at the top of the bimorph. Figure 4 shows the results observed for a pseudo-step field, respectively. The results gave good qualitative agreement with the theory.

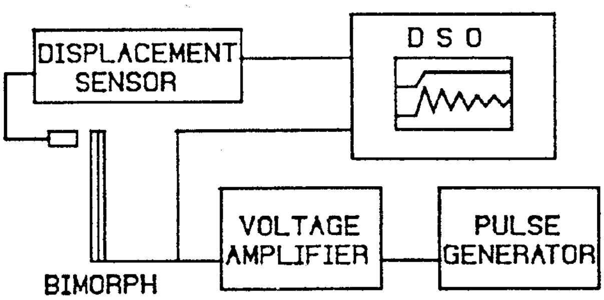


Fig.3. Block diagram of experimental arrangement to measure the response of induced strains of a bimorph actuator to an applied electric field.

Fig.4. Experimental results corresponding to Fig.2.

Furthermore, in the case of the flight actuator using a multilayer piezoelectric actuator and a steel ball[4], a similar pulse voltage control gave a good achievement to damp the rebound of a steel ball.

4. Discussion

When the rise time is slightly deviated from the resonance period, the overshoot and ringing are generated with some modification. Thus our formulation is very useful to calculate the deviation limit of the rise time, corresponding to the allowance of the overshoot or ringing.

References

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