Design of Controller Using the Piezo Actuator

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Abstract

- Piezo Actuator used Sub-nano Scale
- 1 Axis SISO Controller(Discrete-time state-space)

- Piezo Actuator is have to Hysteresis
  - It is Primary Error from Piezo Actuator
- Design for Controller is Base
  - used Pole Placement method
- Hysteresis is Solve to PID Control method and Disturbance Presumer

Prolog

- Issues?

  Nano for manipulating the importance of the precision control device is increasing

- Piezo Actuator : Sub-Nano Scale
- Solve Hysteresis : PID Controller + Disturbance Observer
- Stack Type's Piezo Stage Use

Analysis for Actuator

- PI Co.의 Z Axis Stage(P-543.11.C)
- Bode plot is use to DSA
- Modeling for Second's System & Resonance

$$G(s) = \frac{\omega_1^{\,2}}{s^2 + 2\zeta_1\omega_1 s + \omega_1^{\,2}} \cdot \frac{\omega_2^{\,2}}{s^2 + 2\zeta_2\omega_2 s + \omega_2^{\,2}}$$

$$\omega_1 = 2\pi f_1, \quad \omega_2 = 2\pi f_2$$

$$\zeta_1 = 0.9\,, \quad f_1 = 400\text{Hz} \quad \zeta_2 = 0.15, f_2 = 5\text{kHz}$$

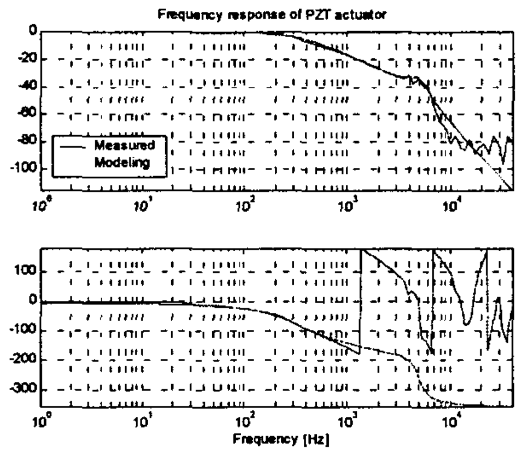
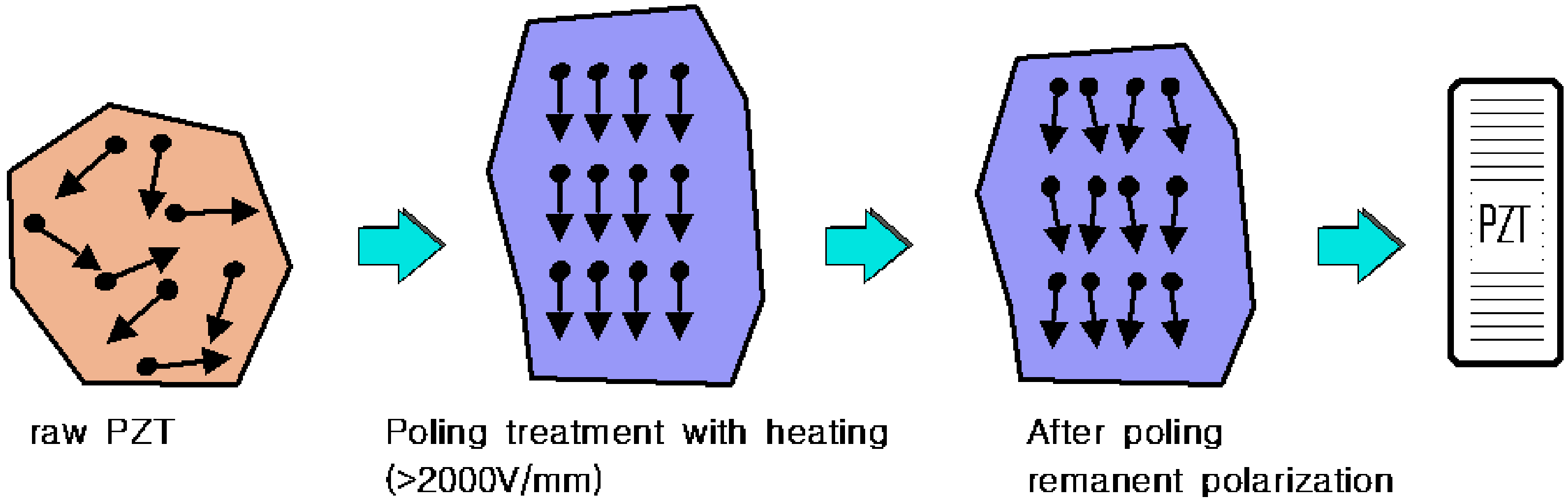


그림 1 Frequency response of the flexure hinge structure stage with piezo actuator

Analysis for Actuator

- Piezo Material?



Analysis for Actuator

- Modeling for Hysteresis
  - Simple differential equation (for Banning)

$$\dot{w}(t) = f(v(t), w(t))|\dot{v}(t)| + g(v(t), w(t))\dot{v}(t)$$

$w(t)$: Hysteresis Displacement

$v(t)$: Input Voltage

if) $a>0$, Log Freq. $\rightarrow$ $f(v) \propto v$, $g(v) \equiv v$

$$f(v(t)) = av(t)$$

$$g(v(t)) = b$$

Analysis for Actuator

if) $0 < 0.5a \leq b < a$

$$\dot{w}(t) = -\alpha w(t)\left|\dot{v}(t)\right| + \alpha a\left|\dot{v}(t)\right| v(t) + b\dot{v}(t)$$

$\therefore$ *Parameter is* $a = 165.02 nm/V$

$b = 133.67 nm/V$

$\alpha = 0.023 V^{-1}$

Control Algorithm

- Transfer Function

  - Discrete-time state-space

$$\dot{x} = Fx + Gu$$

$$y = Hx$$

  - Discrete state-space (use to ZOH)

$$x(k+1) = \Phi x(k) + \Gamma u(k)$$

$$y(k) = Hx(k)$$

$$\Phi = e^{FT_s} \quad , \quad \Gamma = \int_0^{T_s} e^{F\eta} d\eta G$$

System Φ, Γ, H

Control & View Possible

Current Estimator

- Current Estimator Model

$$\hat{x}(k) = \bar{x}(k) + L_c\left[y(k) - H\bar{x}(k)\right]$$

$$\bar{x}(k) = \Phi\hat{x}(k-1) + \Gamma u(k-1)$$

$$u(k) = -K\hat{x}(k)$$

- Current Estimator State Variable

$$\hat{x}(k) = (\Phi - L_c H\Phi)\hat{x}(k-1) + (\Gamma - L_c H\Gamma)u(k-1) + L_c y(k)$$

Current Estimator

- Current Estimator Error

$$\tilde{x}(k+1) = [\Phi - L_c H \Phi]\tilde{x}(k)$$

- Estimator Error State

$$\tilde{x}(k) = x(k) - \hat{x}(k)$$

Controller Design

- Feedback Control Law - u(k)

$$u(k) = -K\hat{x}(k)$$

- Control Algorithm and Feedback Control Law

$$x(k+1) = \Phi x(k) - \Gamma K\hat{x}(k)$$

- Use to Estimator Error State

$$x(k+1) = (\Phi - \Gamma K)x(k) + \Gamma K\tilde{x}(k)$$

Controller Design

- Remove for Normal State Error from Base Input

  - Get Feedforward Gain

  if) Normal State

  $$N_x r \quad = x_r \quad = x_{ss}, \quad H_r x_{ss} \quad = y_m \quad = r, \quad H_r N_x r = r$$

  $$x(k+1) = x(k)$$

  - Use to Discrete state-space (use to ZOH)

  and Normal State $x_{ss} = \Phi x_{ss} + \Gamma u_{ss}$

  $$(\Phi - I) x_{ss} + \Gamma u_{ss} = 0$$

  $$(\Phi - I) N_{ss} + \Gamma N_u r = 0$$

Controller Design

- Presentation Procession from foward-function

$$\begin{bmatrix} \Phi - I & \Gamma \\ H_r & 0 \end{bmatrix} \begin{bmatrix} N_x \\ N_u \end{bmatrix} = \begin{bmatrix} 0 \\ I \end{bmatrix} \quad or \quad \begin{bmatrix} N_x \\ N_u \end{bmatrix} = \begin{bmatrix} \Phi - I & \Gamma \\ H_r & 0 \end{bmatrix}^{-1} \begin{bmatrix} 0 \\ I \end{bmatrix}$$

$$\bar{N} = N_u + KN_u$$

- Control Input Signal from Base Input

$$u(k) = -K\left(\hat{x}(k) - x_r\right) + N_u r$$

$$= -K\hat{x}(k) + \bar{N}r$$

Controller Design

- Hysterisis is Have to Normal state Error

  \- Use to Integral Control for (Error)

  $$e = y - r$$

  $$x_I(k+1) = x_I(k) + e(k) = x_I(k) + Hx(k) - r(k)$$

- Integral Control Gain include Input Control Signal

  $$u(k) = -\begin{bmatrix} K_I & K \end{bmatrix} \begin{bmatrix} x_I(k) \\ \hat{x}(k) \end{bmatrix} + KN_x r(k)$$

Controller Design

- Transfer Function for Disturbance Presumer

$$H(z) = \sum_{i=0}^{l} \alpha_i z^{-i}$$

α_i = Gains of Disturbance Presumer

- Control function include Disturbance Presumer

$$u(k) = -K\hat{x}(k) - \sum_{i=0}^{l} \alpha_i [y(k-i) - \hat{y}(k-i)]$$

Simulation

- Use to Matlab Simulink
- Use to TI Co. TMS320C31 and 16bit AD/DA
- Result of Pole Placement

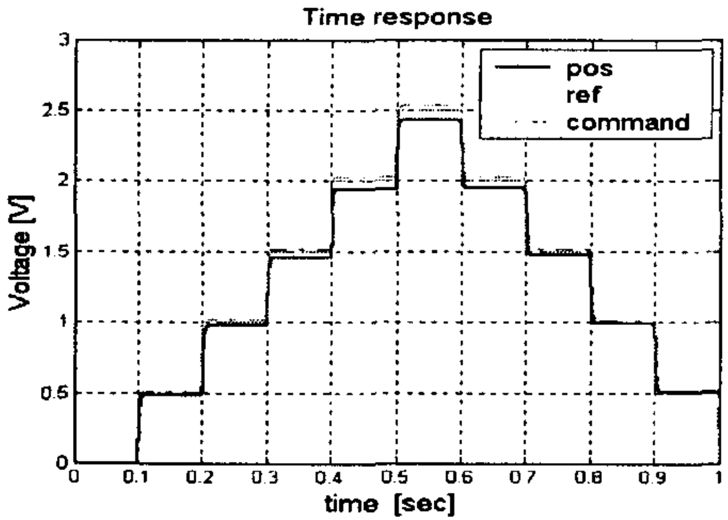


그림 2 Simulation result of pole placement

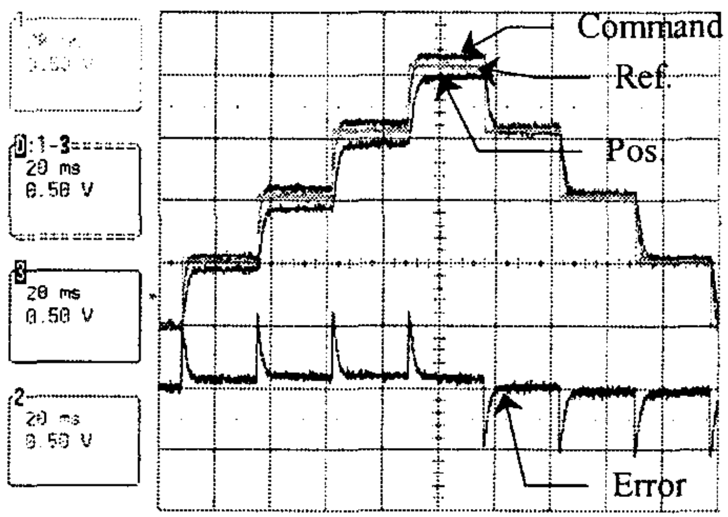


그림 3 Experiment result of pole placement

Simulation

- Result of Integral Control

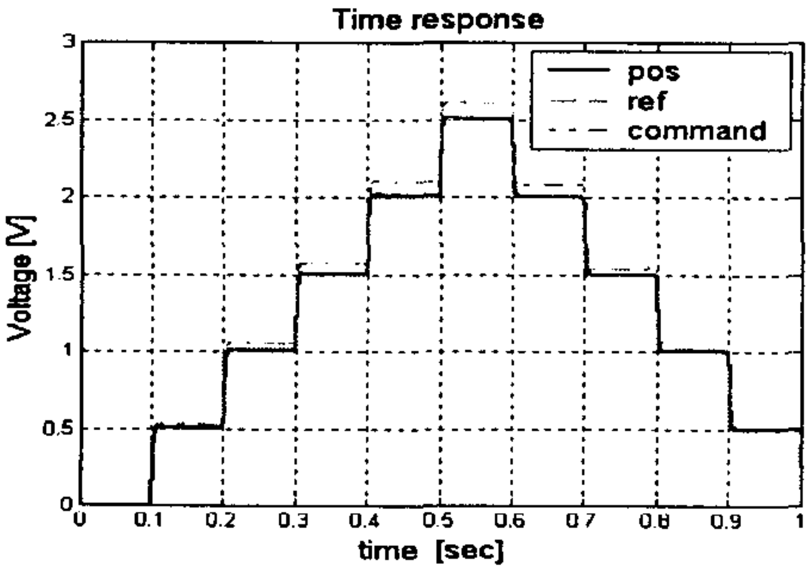


그림 4 Simulation result of integral control

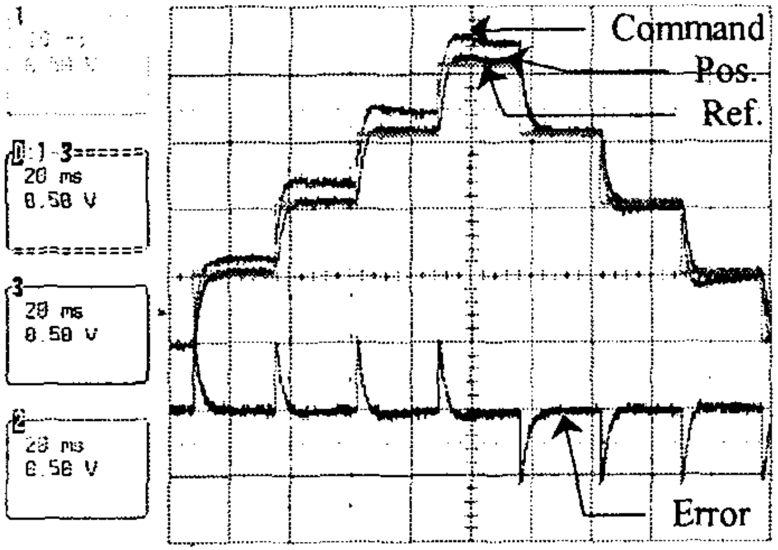


그림 5 Experiment result of integral control

Simulation

- Result of DOB

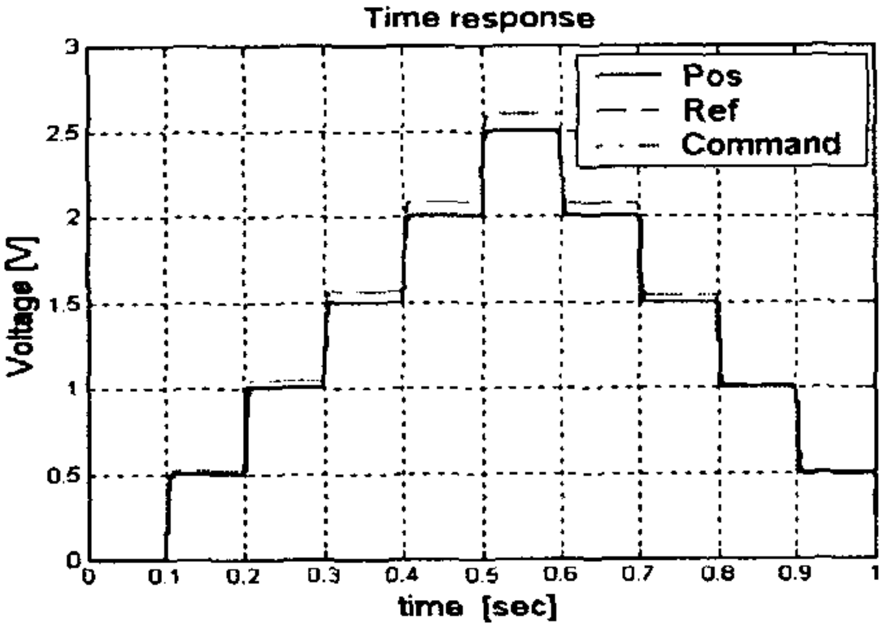


그림 6 Simulation result of DOB

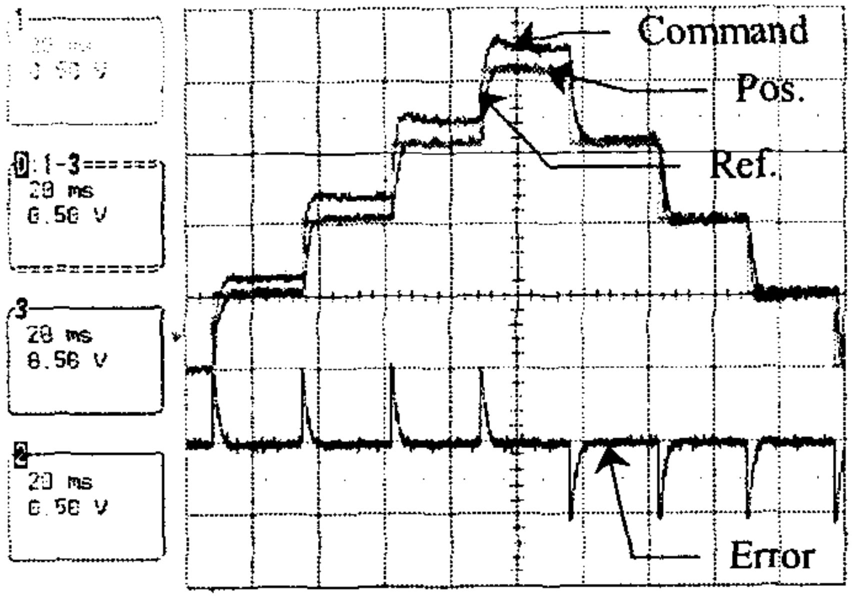


그림 7 Experiment result of DOB

Result

- Comparative Analysis For Position control Upgade
- Hysteresis solved use to PID Controller
- Hysteresis solved Integral Control and Disturbance Presumer from Pole Placement

- View Simulation and Test
- View Solve to Hysteresis from Control Algorithm