Positioning control of pzt actuators using neuro control with hysteresis model (ICCAS 2003)

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Abstract: In this paper, in order to improve the control performance of piezoelectric actuator, an integrated control structure is proposed. The control structure consists of inverse hysteresis model , to compensate the hysteresis nonlinearty problem, and feedforward - feedback controller to give a good tracking performance. The inverse hysteresis model and neural network are used as feed-forward controller, and PID controller is used as a feedback controller. From diverse experiments it is concluded that the proposed control scheme gives good tracking performance than the classical control does.

Keywords: piezoelectric, ferroeletric, hyseresis, nonlinearty, feedforward, hyseresis model, inverse modeling

1. INTRODUCTION

Many efforts have been made for improving the hysteresis behaviour of piezoelectric actuators. The schemes can be classified into three categories: 1) using electric charge to drive piezoelectric actuators instead of applied voltage, 2) using feedforward nonlinear models in driving the actuators, and 3) using closed-loop control schemes. In the first scheme, Newcomb and Flinn[1] proposed that applying electric charge as a control input instead of voltage could reduce the hysteresis nonlinearity. Kaizuka and Sui[2] also proposed a similar method to reduce the hysteresis nonlinearity of piezoelectric actuators by inserting a compensating capacitor in series with the piezoelectric actuator and using a simple voltage drive. Thease approaches, however, require the use of specially designed charge drive amplifier and cause a reduction in the sensitivity of the displacement.

In the second scheme, Jung and Kim[3] presented a feed-forward control method with three different deterministic models to reduce the hysteresis effect in piezoelectric actuators. In the scheme, the model assumes that the hysteresis nonlinearity of piezoelectric actuators has a local-memory. In the third scheme, Ge and Jouaneh[4] presented a control algorithm which incorporates a feedforward loop with a PID feedback controller, where hysteresis nonlinearity of the piezoelectric actuator is modified in the feedforward loop by using the classical Preisach model. Kim and Lee[5] adopted a neural network to learn the hysteresis nonlinearity, and used PID feedback controller as feedback controller.

In this paper, a hysteresis model that can represents hysteresis nonlinearity of the piezoelectric actuator is presented and the model is converted to inverse-hysteresis model in which the input to the model is applied voltage and the ouput to the model is the displacement of the actuator. The proposed inverse-hysteresis model gives good tracking performance, however the tracking error is quite bad around the vicinity of the turning point of the trajectory. Therefore a neuro-PID control system is incorporated to the inverse-hysteresis model in parallel fashion. The aim of the neuro-PID controller is to compensate both the modeling error of the inverse-hysteresis model and the unknown nonlinearity factor such as friction.

2. Hysteresis Modeling of Piezoelectric actuators

We can derive a mathematical equation that describes the geometrical relations between input voltage and output displacement of piezoelectric actuators. The used parameters for the equations are shown as in Fig.1.

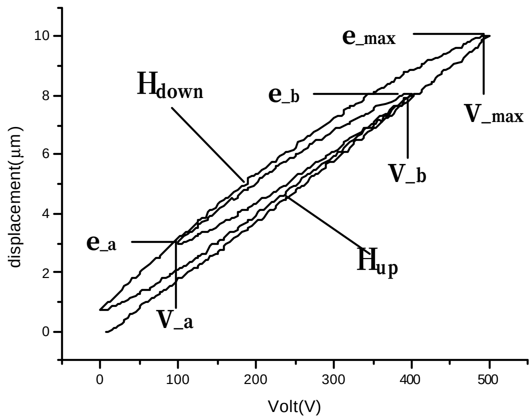

Fig.1 Parameters for mathematical modeling of hysteresis loops

The used parameters can be described as follows. e: current displacement, V: current applied voltage, V_a: minimum voltage of the minor loop, V_b: maximum voltage of the minor loop, e_a: minimum displacement of the minor loop, e_b: maximum displacement of the minor loop, e_max: maximum displacement of the major loop, V_max: maximum applied voltage of the major loop, H_{up} : curve fitting equation for the ascending curve of the major loop, and H_{down} : curve fitting equation for the descending curve of the major loop. From the geometrical relationship and the parameters described in Fig.1, modeling equations are proposed to Eq.(1) and Eq.(2), so called hysteresis modeling of the piezoelectric actuator:

$$\mathbf{e} = \mathbf{H}_{up}(\mathbf{V}-\mathbf{V}_{\_a}) + \mathbf{e}_{\_a}, \quad (1)$$

$$\mathbf{e} = \mathbf{H}_{down}(\mathbf{V}-\mathbf{V\_b}+\mathbf{V}_{\_max}) + \mathbf{e}_{\_b} - \mathbf{e}_{\_max}. \quad (2)$$

Eq.(1) is the modeling equation for any point at the ascending curve of the minor loop, whereas Eq.(2) is the modeling equation for any point at the descending curve of the minor loop. In Eq.(1) and Eq.(2), the applied voltage to the piezoelectric actuator, V, is input variable, and the displacement of piezoelectric actuator, e, is output variable which is considered as the estimation of actual displacement of the actuator.

However, Eq.(1) and Eq.(2) are not proper in control applications. In the control area, inverse hysteresis model of the piezoelectric actuator, the inverse forms of Eq.(1) and Eq.(2), is preferred. Eq.(3) and Eq.(4) denote the inverse hysteresis model of Eq.(1) and Eq.(2), respectively.

$$V = V_{\_a} + H^{-1}_{up}(e - e_{\_a}), \quad (3)$$

$$V = V_{\_b} - V_{\_max} + H^{-1}_{down}(e_{\_max} - e_{\_b} + e). \quad (4)$$

Fig.2 shows the inverse hysteresis modeling for the hysteresis loop shown in Fig.1

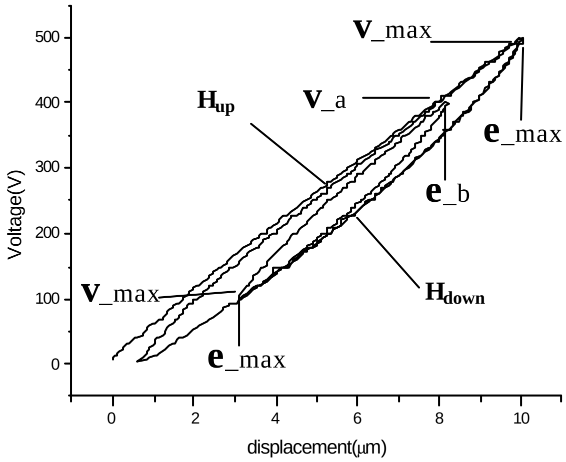

Fig.2 Inverse hysteresis model

3. Control system design for piezoelectric actuators

We can compensate hysteresis nonlinearity of piezoelectric actuators using the hysteresis modeling or inverse hysteresis modeling. However, there can be unknown nonlinear element such as friction in addition to the hysteresis nonlinearity. In order to compensate both the nonlinearities of piezoelectric actuators, we proposed a integrated controller that use a neuro-PID controller with hysteresis compensation capability. The block diagram of the proposed controller is shown in Fig.3. In Fig.3 V_h is the compensated voltage developed by inverse hysteresis model, which compensates the hysteresis nonlinearity caused by piezoelectric actuator. V_{pid} is the control voltage from PID controller to minimize the position and velocity tracking error. In addition to the hysteresis compensation and PID controller, in the proposed control structure, a neural network controller is added to compensate unknown nonlinear factor such as friction.

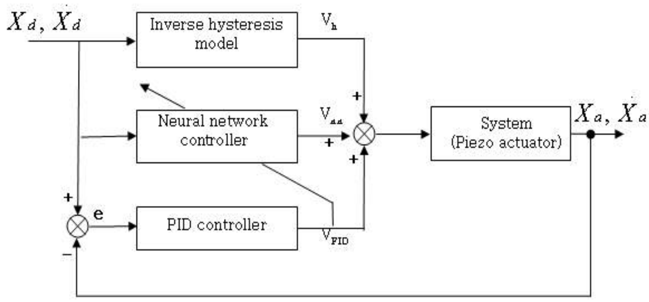

Fig.3 Proposed control system structure

4. Experiment

4.1 Experimental setup

In order to compare the tracking performance of the proposed controller with general classical controller, we carried diverse experiments. The piezoelectric actuator, amplifier for the piezoelectric actuator, and capacity-type displacement sensor unit are the products of PI(Physik Instrument), German. The maximum stroke of the piezoelectric actuator is 20 μm, and the displacement sensor can give nm level resolution with 50 um stroke. A/D and D/A board is used with the model PCL-818L from Advantech Co.

4.2 Tracking experiment using inverse hysteresis model

In order to model the inverse hysteresis characteristic of the piezoelectric actuator by using Eq.(3) and (4), major loop of the hysteresis curve should be model into mathematical form. First, major hysteresis loop is acquired in experiment, and the experimental data is converted into mathematical equation, i.e. 3rd order equation, using curve fitting method. The mathematical form for the ascending and descending curve of the major hysteresis loop can be seen in Fig.4

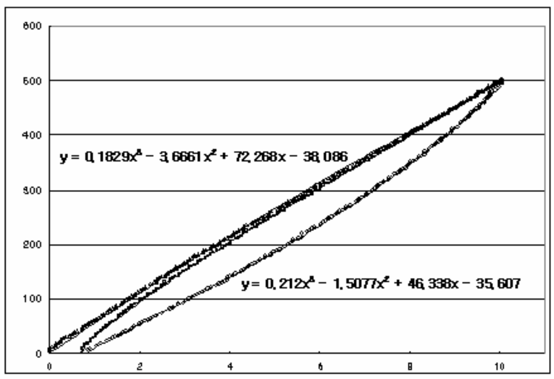

Fig.4 Curve-fitting equation for the experimental hysteresis loop

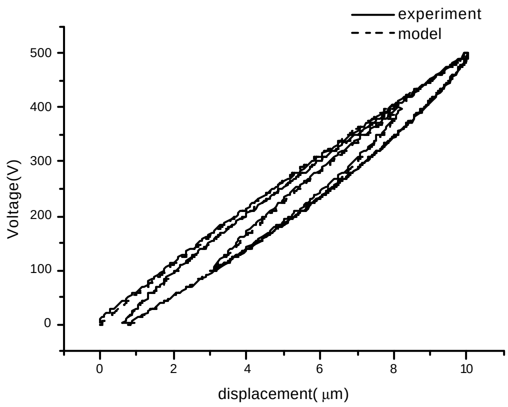

Fig.5 Comparison of inverse hysteresis curve

Using above curve-fitting equation and Eq.(3) and (4), inverse hysteresis model can be acquired. To prove the performance of the inverse hysteresis model, hysteresis curves from model and experiment are shown and compared as in Fig.5. From Fig.5 we can conclude that the inverse hysteresis model represents quite well the real hysteresis characteristic.

Next, we did an experiment in which desired trajectory is sinusoid with amplitude of 3 um, frequency of 3 Hz, and the initial position of the trajectory is 4.5 um, as shown in Fig.6. And the tracking errors of PID only, PID with hysteresis, and neuro-PID with hysteresis are shown in Fig.7, Fig.8, and Fig.9, respectively. Through the experiments, we can see that the case using the hysteresis compensator plus neuro-PID controller has better tracking performance than the case using inverse hysteresis compensator plus PID controller.

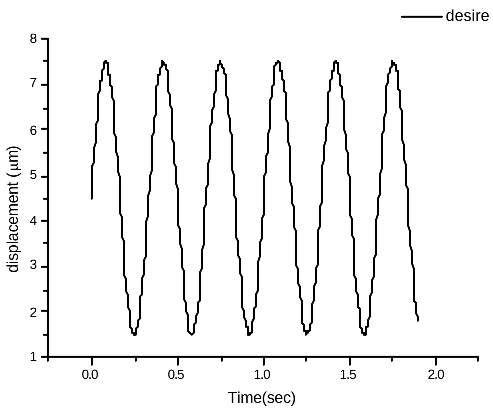

Fig.6 Desired trajectory with sinusoidal pattern

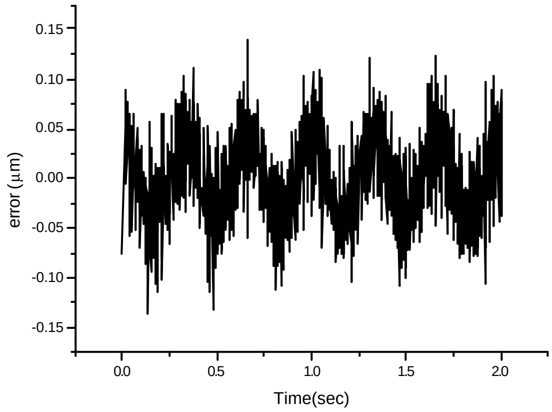

Fig.7 Tracking error in using PID controller

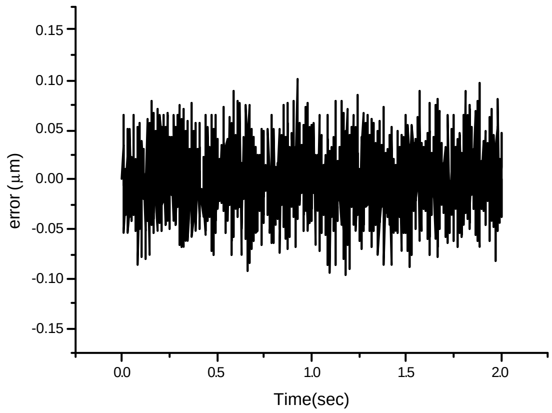

Fig.9 Tracking error in using neuro-PID controller with inverse hysteresis model

5. Conclusions

In this paper, in order to improve the control performance of piezoelectric actuator, an inverse modeling scheme is proposed to compensate the hysteresis nonlinearty problem. And feedforward - feedback controller is proposed to give a good tracking performance. The Feedforward controller consists of inverse hysteresis model and neural network, whereas PID control is used as a feedback controller. To show the feasibility of the proposed controller, some experiments have been carried out. From the experiments, we have the following results: the PID controller with inverse-hysteresis model can not fully describe the moving pattern of piezoelectric actuators, and there exists un-modeled nonlinearity such as friction except for the hysteresis nonliearity. However, the neural-network based PID controller, with inverse-hysteresis model, can further reduce un-modeled nonlinearities.

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References

[1] Newcomb, C.V. and Flinn, I., Improving the Linearity of Piezoelectrid Ceramic Actuators. Electronics Letters, 1982, 18(11), 442-444.

[2] Kaizuka, H. and Sui, B., A simple way to reduce hysteresis and creep when using piezoelectric actuators. Japan J. Appl. Phys, 1988, 27(5), 773 776.

[3] Jung, S. and Kim, S., Inprovement of scanning accuracy of

PZT piezoelectric actuators by feedforward model-reference control. Precision Eng. 16(1), 49-55.

[4] Ge, P. and Jouaneh, M., Tracking Control of a Piezoceramic Actuator. IEEE transactions on control systems technology, 1996, 4(3), 209-215.

[5] Kim, H.S., Lee, B.R., and Park,K.Y., Precision position control of a piezoelectric actuator using neural network. Korean Society of Precision Engineering, 1999, 16(11),9-16.