Hysteresis Modeling in a Piezoelectric Nanopositioner Stage

A. Telba and Wahied G. Ali

***Abstract*—Piezoelectric materials have many advantages, such as: high stiffness, a high frequency response, and high resolution. It has been widely used in reducing vibration system, but hysteresis confines its use. This paper aims to develop the hysteresis model for a single axis piezoelectric nanopositioner stage at different operating points. The adopted methodology is to compare between the analytical model using MATLAB and the real time results using LabVIEW. The experimental results for real measurements had been acquired for the piezoelectric nanopositioner stage using data acquisition system from National Instruments. The experimental setup is described and output results for simulation and real time measurements are compared to validate the adopted approach.**

***Index Terms*—Piezoelectric Materials, Actuators, Hysteresis, Modeling.**

I. Introduction

HYSTERESIS is a nonlinear phenomenon occurring in many engineering devices such as the micro and nano piezoelectric actuators (PZA), the shape memory alloys (SMA), and the ferromagnetic elements [1-4]. A system with hysteresis is usually difficult to describe accurately and may result in unstable behaviors if not controlled appropriately. Therefore, an accurate model of hysteresis is critical in order to develop suitable control algorithms or applications with these systems [5]. Several models have been developed to characterize systems with hysteresis and the classical Preisach model (CPM) has been known as the most familiar one to characterize hysteresis behaviors [6]; this model can be further represented by an infinite but countable first order [7]. Modeling, simulations and experimental work of piezoelectric nanopositioning actuator had been done. Hysteresis is one of the most effects in nanopositioning system; in this case the PI 754 nanopositioning actuator system is used. Classical actuators (electromagnetic, hydraulic and pneumatic) are the most used in the industry; new technologies based on different physical principles are being developed. In applications where the size of the actuator has to be miniaturized, or where fast response and high resolution are needed, the classical actuators fail to respond appropriately. For this reason, non-classical technologies are becoming more relevant. Among them, the piezoelectric actuators are proving to be a reliable solution for many engineering applications, ranging from micro and nano positioning applications (machine tools, optic devices or modern microscopes biomedical, nano-robots, and automotive).

The paper is organized as follows: Section II describes the hysteresis behavior in piezoelectric materials. Section III presents the experimental results. Section IV concludes the paper and highlights the main points.

Manuscript received January 12, 2011; revised April 8, 2011. This work was supported in part by supported by NPST program by King Saud University, Project number "08-NAN388-02".

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II. Pizoelectric Materials Hysteresis

Piezoelectric materials' hysteresis is the different displacement behavior at the same voltage values either ascending or descending. As shown in figure 1, ΔH is maximum displacement different. Δ H reflects piezoelectric materials' hysteresis [8].

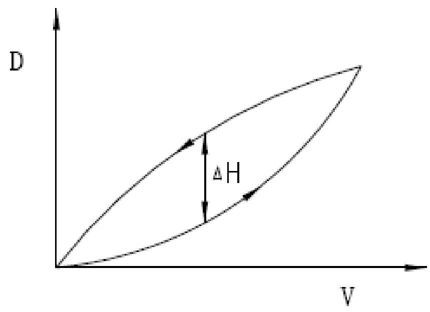

Fig .1. Piezoelectric materials' hysteresis [8].

Many researchers have been interested with hysteresis behavior in piezoelectric materials. In general, hysteresis' research has two methods: the former is to find the hysteresis reason of piezoelectric materials, such as domain model in [9-10]; the latter is to consider hysteresis as a black box and identify the hysteresis characteristics using a numerical analysis approach, such as Preisach model in [11], slide model in [12], and neural networks model in [13]. Discrete Preisach model using numerical is shown in figure 2. In our case study increasing the number of iterations, the model will present the real model ,the 3rd order polynomial used to solve equations of (1) and (2).

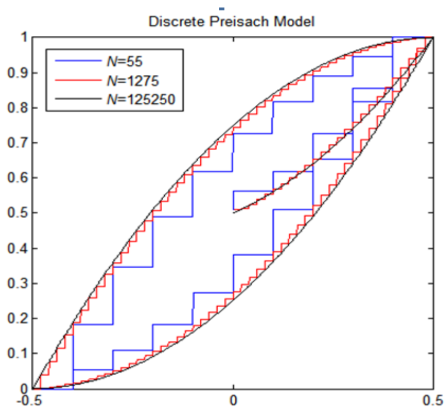

Fig .2. Discrete Preisach model using numerical analysis [6].

$$F0(x) = a0 + a1 * x + a2 * x2 + a3 * x3 \quad (1)$$

$$G0 (x) = b0 + b1 * x + b2 * x2 + b3 * x3 \quad (2)$$

In fig 3, horizontal axis denotes apply voltage, vertical axis denotes displacement of piezoelectric actuator in micrometers. When voltage increased, the displacement increased related to the input voltage.

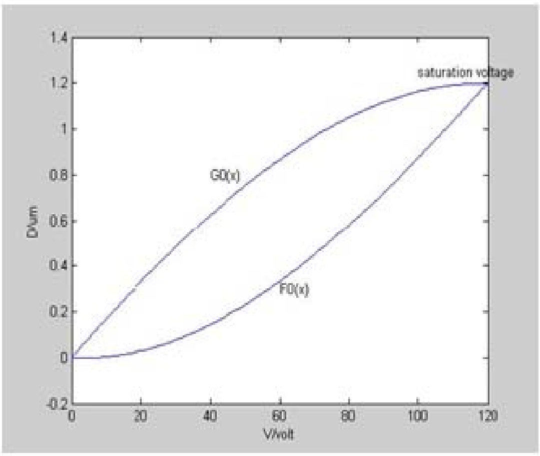

Fig .3. Model using numerical analysis [8].

The maximum displacement is regarded to 100V in nanpositioning; this voltage is named saturation voltage. When voltage descends from saturation voltage to zero, the displacement descends. The displacement of descending is different than the displacement of ascending. The two curve don't change, and are named limit G0(x) and F0(x) [2]. In order to describe the limit curves, using least quadric (LQ) fit the data. From simulation results, it has been noticed that the two curve G0(x) and F0(x) come out as same as before then polynomial degree increase, the model's precision improve. So we use n=3, and fit it using equation (1) and (2).

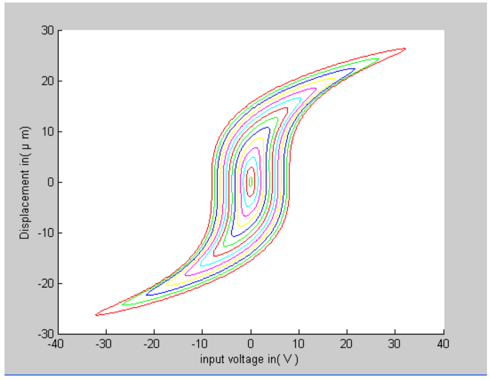

Fig. 4. Analytical model of hysteresis simulated by MATLAB.

III. Experimental Results

In this section, we used the proposed real-time experiments. Figure 5 shows the experimental setup which consists of: Industrial PC from National Instruments (PXI system) with an installed LabVIEW software, data acquisition card (DAQ NI 6361), single axis nanopositioner PI-752.21C with a displacement measurement using capacitor, signal conditioning circuit for the displacement measurements, and a piezoelectric power amplifier.

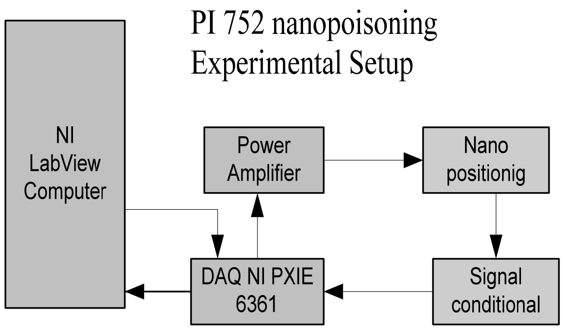

Fig. 5. Experimental setup.

Fig. 6 represents the LabVIEW code to acquire the hysteresis behavior for PI-752.21C nanopositioner. DAQ assistant VIs is used to interface the program with real time measurements.

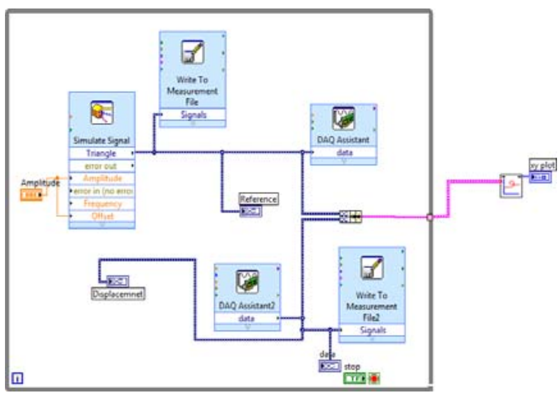

Fig. 6. LabVIEW Code for real time measurements.

ISBN: 978-988-19251-4-5
ISSN: 2078-0958 (Print); ISSN: 2078-0966 (Online)

The real time displacement is recorded in both text file and real time output as shown in figure 7 and measured both input voltage in x axis and displacement of the nanopositioner in y axis. The figure to the right up corner is the relation of traveling in both ascending and descending of the piezoelectric nanopositioniner.

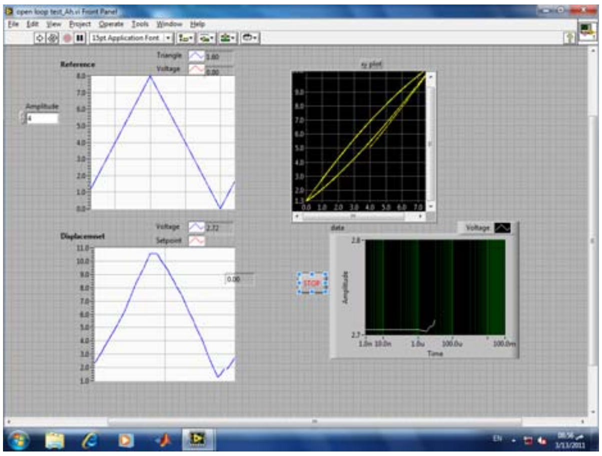

Fig.7. Real time measurement of piezoelectric nanopositioniner.

In the above figure, the left up corner refers to the input voltage is triangular wave with peak of 4V and using frequency of 10Hz for real time testing of the simulated signal while the left down corner refers to displacement of Nano-Positioning Piezoelectric while the right up is referred to the Hysteresis curve from real time at input 4V peak triangular wave. In the experimental work using different peak voltage (1V, 2V, 3V, V4, 5V) with same frequency of 10Hz, the Hysteresis Measured in real image as shown in fig 7 and text file and plotted using MATLAB.

IV. Conclusion

This paper investigated the hysteresis modeling for a single axis nanopositioner stage. The adopted approach is to acquire the real time characteristics experimentally; then store it in a text file and redraw it using MATLAB. The simulated model in MATLAB is identified using a 3 rd order polynomial. The obtained model is approved by comparing its behavior to that obtained by real time measurements, and the identification error can be measured in LabVIEW program. This error can decrease hysteresis effectively in integrating with speed of the Nanopositioning stage. Real time measurement is acquired and the hysteresis at different input voltage is measured.

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