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ЛАБОРАТОРНАЯ ТЕХНИКА

REAL TIME MEASUREMENTS OF HYSTERESIS IN A PIEZOELECTRIC NANOPOSITIONER STAGE

Ahmed A. Telba, Wahied G. Ali

Electrical Engineering Department, College of Engineering, King Saud University
P.O. Box-800, Riyadh 11421, Saudi Arabia
e-mail: atelba@ksu.edu.sa, wahied@ksu.edu.sa,
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This paper aims to develop a hysteresis model for a single axis piezoelectric nanopositioner stage at different operating points. The adopted methodology compares results based on the developed analytical simulation model using MATLAB with real time results using LabVIEW. The experimental results for real time measurements had been acquired for the piezoelectric nanopositioner stage using data acquisition system from National Instruments (NI). The experimental setup is described. The simulation and real time measurements results are compared to validate the adopted approach.

I. INTRODUCTION

Hysteresis is a nonlinear phenomenon occurring in many engineering devices such as 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 for 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 further be represented by an infinite, higher order of polynomial or using analytical model [7].

Modeling, simulations and experimental work on piezoelectric nanopositioning actuator had been done to study the effect of the hysteresis at different input voltage before and after the system saturation (maximum travelling range). Hysteresis is one of the most effects in nanopositioning system. In this case the P-752.21C nanopositioning actuator system is used. This paper aims to develop a hysteresis model for a single axis piezoelectric nanopositionner stage at different operating points.

The adopted methodology compares results based on the developed analytical simulation model using MATLAB with real time results using LabVIEW. Section II describes the hysteresis behavior in piezoelectric actuator and solution of analytical expression. Section III presents the experimental results using real time measurements of piezoelectric actuator model (P-752.21C) [8, 9] with a maximum traveling range of 30 μm.

II. PIEZOELECTRIC MATERIALS' HYSTERESIS

Piezoelectric materials' hysteresis is the different displacement behavior at the same voltage values either ascending or descending. As shown in Fig. 1, ΔH is the maximum displacement difference in traveling range of the two motion of the piezoelectric actuator. ΔH reflects piezoelectric materials' hysteresis [10].

Many research activities have been reported for hysteresis behavior in piezoelectric materials. In general, research on hysteresis uses one of two methods. The first method is to find the hysteresis reason of piezoelectric materials, such as domain model in [11, 12]. While the second method for modeling is to consider hysteresis as a black box and identifies the hysteresis characteristics using a numerical analysis approach, such as Preisach model in [12], slide model in [13], and neural networks model in [14].

Discrete Preisach is a well known model for hysteresis in numerical analysis. Another model using analytical expression is shown in the equation below using MATLAB to plot the hysteresis family of curves at dif-

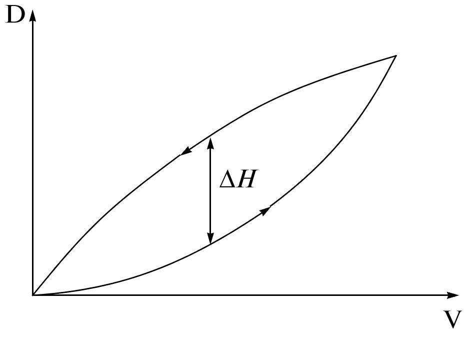

Fig. 1. Piezoelectric materials' hysteresis [10].

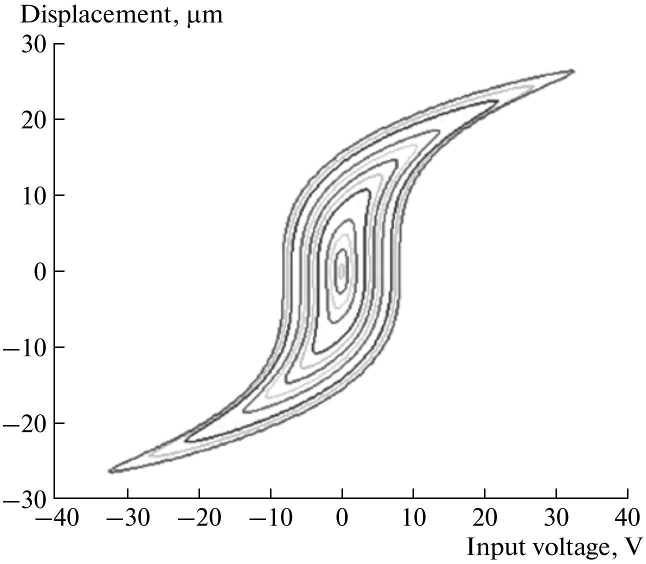

Fig. 2. Analytical model of hysteresis simulated by MATLAB.

ferent values of the related variables. The family of hysteresis loops can be described by a generalized transcendental equation in parametric form as follows:

$$x(\alpha) = \pm a\cos^{m}\alpha \pm b_x\sin^{n}\alpha$$
$$y(\alpha) = b_y\sin\alpha \qquad (1)$$

where a is the split point coordinate; b_x, b_y are the saturation point coordinates; m, n are integer numbers: $m = 1, 3, 5$; $n = 1, 2, 3$; and α is a real parameter ($-\infty \le \alpha \le +\infty$). Using MATLAB code to solve equation (1) and plot the result at different values of variables is shown in Fig. 2. In Fig. 3, the horizontal axis denotes the applied voltage, and the vertical axis denotes the displacement of piezoelectric actuator in micrometers. When the voltage increased, the displacement also increased until reaches saturation voltage. The saturation voltage depends on the travelling range of piezo actuator.

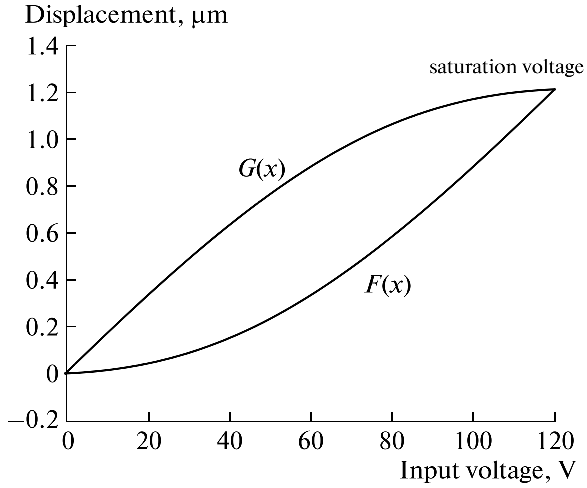

Fig. 3. Model using numerical analysis [9].

The maximum displacement is regarded maximum input voltage of nanpositioning; this voltage is referred to as the saturation voltage. When the applied voltage descends from the saturation voltage to zero, the displacement descends. The displacement of descending is different than the displacement of ascending. The two curves don't change, and are named limit $G(x)$ and $F(x)$ [2].

III. EXPERIMENTAL RESULTS

In this section, the proposed system used for real-time experiments is shown in Fig. 4. The main core of the setup includes National instruments simulation and real time measurements tool LabVIEW which is used to simulate and transfer real data to the nano system through the data acquisition card (DAQ NI 6361 24 Chanel Data Transfer System).

In Fig. 5 LabVIEW Code for real time measurements consists of Signal Express: Simulates a triangle wave, DAQ Assistance Express, write the measure-

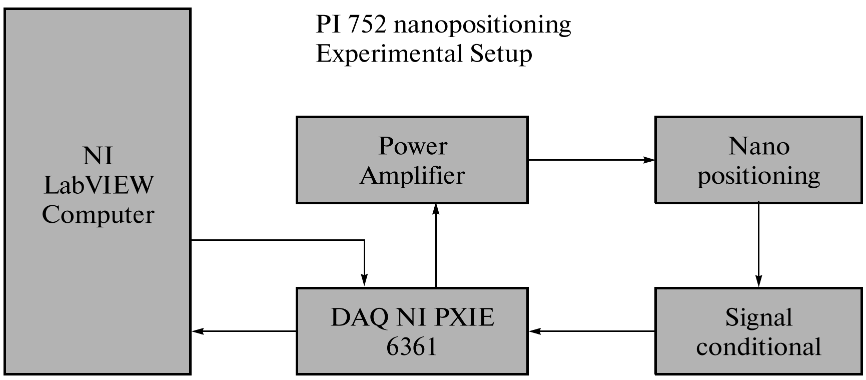

Fig. 4. Block Diagram for Experimental setup.

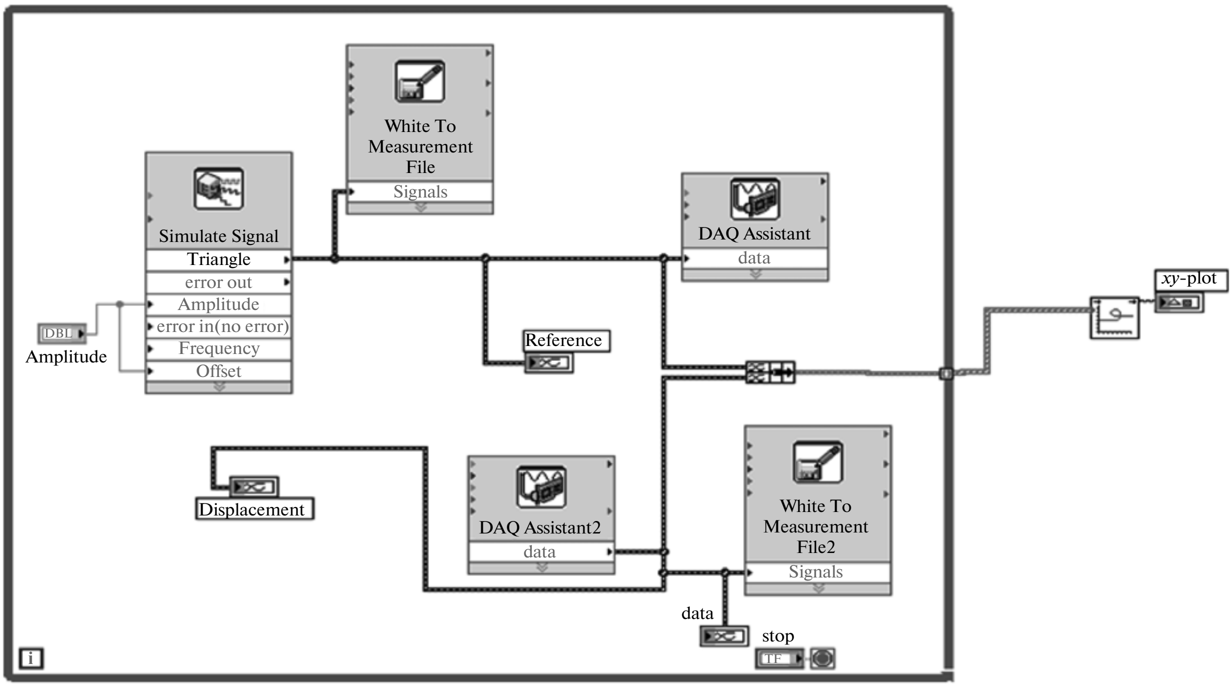

Fig. 5. LabVIEW Code for real time measurements.

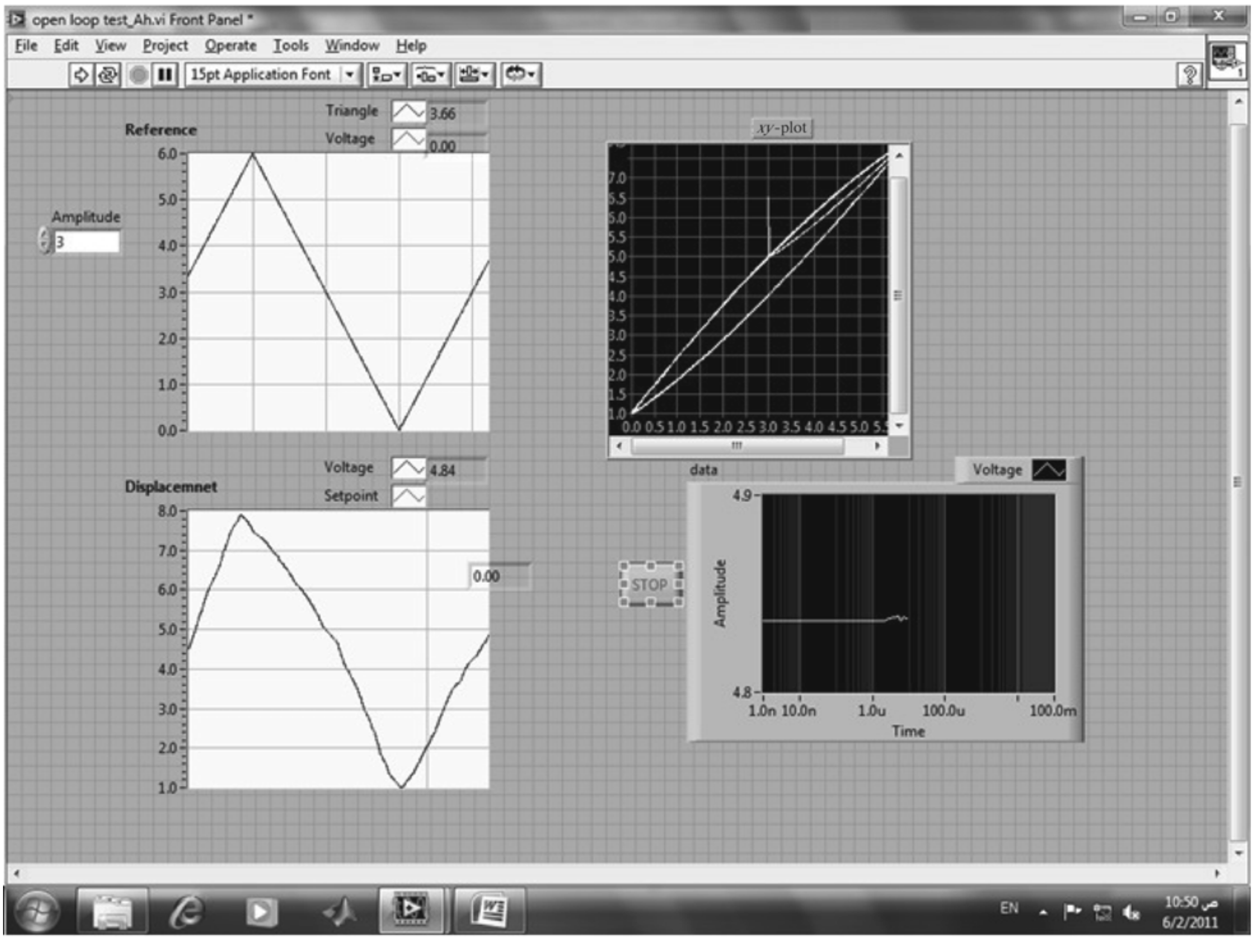

Fig. 6. Hysteresis in Piezoelectric Actuator using LabVIEW.

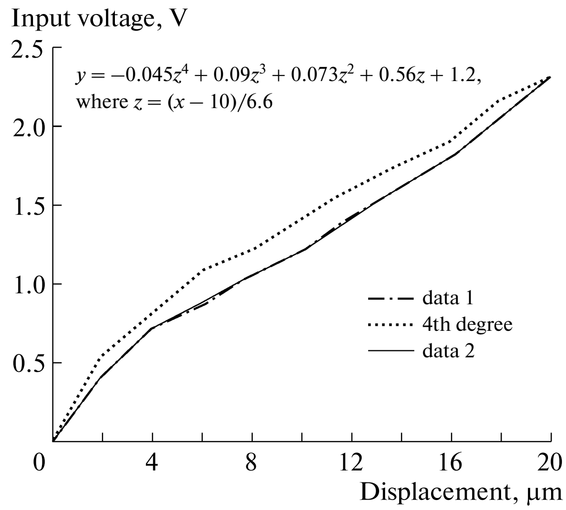

Fig. 7. Hysteresis in piezoelectric actuator using 4th degree of polinomial.

ments to file, bundle by name all in for loop for multi measurements, *xy*-plot for hysteresis measurements at different input voltage, the output of the measurements file transferred to excel sheet to draw the output. Figure 6 shows the output of real time measurements of hysteresis in Piezoelectric Actuator. Two sets of experiments were carried out. The first set of experiments uses a 10 Hz triangular wave. This is followed by varying the amplitude linear motion with varying velocity to demonstrate the capability to model rate-dependent. The last experiment is to fixing the frequency with varying the amplitude of the triangular wave.

Using the real data form output text file was plotted and curve fitting using the 4th degree polynomial for fitting data as shown in Fig. 7. The fitting equation and its coefficients are:

$$y = p_1 z^4 + p_2 z^3 + p_3 z^2 + p_4 z + p_5,$$
$$p_1 = -3.2816\text{e}{-005}, \quad p_2 = 0.0016491,$$
$$p_3 = -0.028874, \quad p_4 = 0.29472, \quad p_5 = 0.014196.$$

Figure 8 shows the different operation of measurements for piezoelectric actuator with triangular wave of different amplitude and same frequency and measure the real time hysteresis in *x*-axis is the input voltage and in *y*-axis is the displacement in (μm). Figure 8 shows the error from real measurements of the displacement related to the time.

IV. CONCLUSION

In this paper, we have verified a hysteresis model for a single axis piezoelectric nanopositioner stage at different operating points using an experimental setup using LabVIEW. The adopted methodology is to compare results between the analytical model using MATLAB and the real time results using LabVIEW. The experimental results for real time 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 measure-

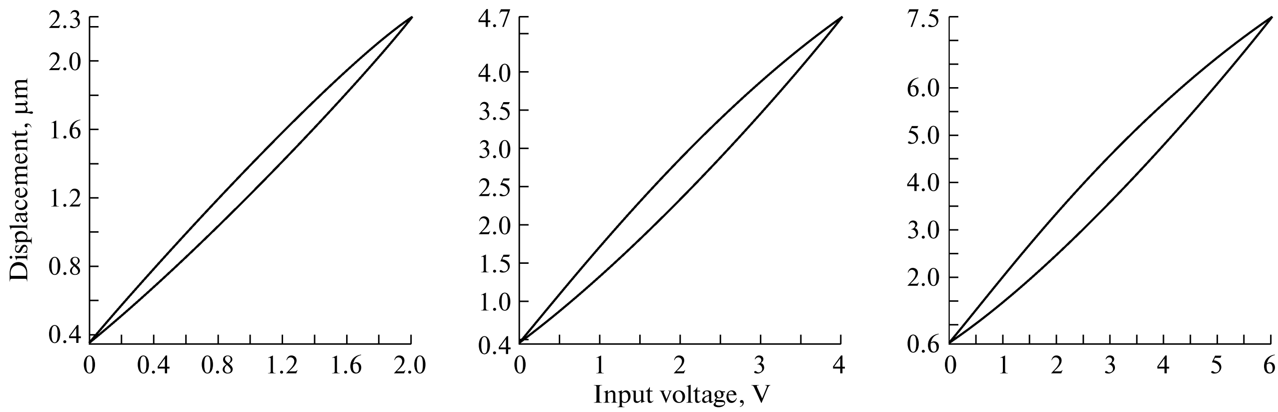

Fig. 8. Hysteresis in Piezoelectric Actuator at Different input voltage values.

ments are compared to validate the adopted approach. Measured real time hysteresis using the setup and simulation results are presented and discussed. It is proved by experimental tests that the model can describe the hysteresis of piezoelectric actuator, and the error between simulated and measured results is presented.

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