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THE CONTROLLABILITY AND BEHAVIOR ANALYSIS OF PIEZOELECTRIC BENDING ACTUATOR ASSEMBLY

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Abstract. *In this paper the characteristics of PL112.10 plate piezo-bender are analyzed. Simple numeric model of piezo element was created and compared with real data. The system of accurate position control of piezo element was designed and its features were discussed in context with piezo-bender`s hysteresis and sampling frequency. The achieved results are presented along with the description of used methods and equipment including the description of constructed testing appliance.*

Keywords: piezoelectric actuators, controllability, control system

STEROWALNOŚĆ I ANALIZA ZGINANIA SIŁOWNIKA PIEZOELEKTRYCZNEGO

Streszczenie. *Artykuł opisuje zastosowanie i badanie piezoelementu PL112.10. Autorzy zidentyfikowali parametry symulacyjne piezo, wykonali jego model oraz porównali zachowanie modelu i rzeczywistego elementu piezo. Dalsze prace skupione były na budowie precyzyjnego systemu regulacji położenia wykorzystującego badany element. Pod uwagę wzięto jego histerezę, a badania przeprowadzono dla różnych częstotliwości próbkowania. Końcowa część artykułu zawiera opis stosowanych metod i urządzeń pomiarowych oraz uzyskane wyniki badań.*

Słowa kluczowe: siłowniki piezoelektryczne, pozycjonowanie, sterowanie

Introduction

The phenomenon of piezoelectricity was first discovered by Jacques and Pierre Curie in 1880, but one of the first important applications of piezoelectric materials took place in 1917 when Paul Langevin used an ultrasonic transducer in his research of underwater acoustics, particularly focusing on submarines detection through echo location using high frequency ultra sonic waves. However problems with production of piezoelectric crystals based on Potassium sodium tartrate (The Seignette's salt) delayed the mass production wide usage of this materials for many decades.

Nowadays piezoelectric materials can be found in many applications such as sound generation or detection, micro balancing and ultrafine focusing optical and other accurate assemblies, noise and vibration damping etc. Aim of this work is to analyze properties of piezo-bender and design a high-precision control system robust to piezo hysteresis, variable input error and noise feedback signal. The purpose of this research is in ultrafine flow control of application specific servo valves.

1. Assembly description

The piezo element used for the research was PICMA® Bender Piezo Actuator PL112.10 with operating voltage ±30 V and displacement range ±80 (±20%) µm. Resonant frequency of selected piezo actuator is 2000 Hz ±20 %. One of the most important features of not only this piezo bender is a strong hysteresis, which is graphically depicted in fig. 2. For analysis and comparison the non-hysteresis numerical model was created using numeric dynamic system identification methods. Model parameters were identified by finding the minimum of an unconstrained multivariable optimizing function created in Matlab.

The bender was powered by High Power Monolithic Operational Amplifier OPA541 connected to dSPACE DS 2102 DAC. Position feedback was realized by HBM WETA1/2 E11684 Inductive Displacement Transducer.

For the measurement, identification of parameters and control the dSPACE modular measurement system was used. dSPACE is a producer of development and testing tools for mechatronic control systems used widely in automotive or aviation industry as well as at research plants. Used assembly consists of DS2002 MUX ADC board with thirty two analog input channels and DS 2102 DAC with eight 16 bit output channels and 2 µs settling time. The voltage range of dSPACE modules was set on +/-10 V except the case of measured signal from displacement sensor where sufficient +/-5 V was chosen in order to achieve higher precision.

2. Measurements

The practical experiment with model identification and controller testing was implemented on described hardware using low sampling frequency of 1 kHz and subsequently even lower 100 Hz sampling frequency was tested and results were compared. The influence of sampling frequency on system parameters and behavior is described further. Transfer function with identified parameters of numeric model is as follows:

$$x = \frac{0.09134}{1.336\mathrm{e}^{-9} * s^3 + 2.004\mathrm{e}^{-6} * s^2 + 0.001753 * s + 1}$$

The range of response variable measured by displacement sensor according to presented settings was 0.030 V to 0.220 V corresponding to driving voltages -30 V to 30 V respectively. Measurements were carried out using three different types of driving signal functions: square signal, continuous 1 Hz sinus function and semi-continuous linear function signal. The identification measurements used optimized progression of square signal in addition.

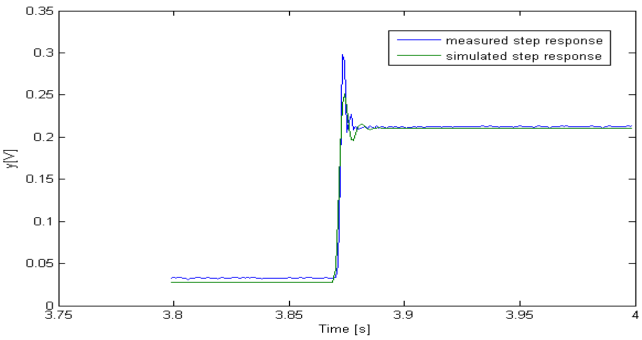

Fig. 1. Comparison of real and simulated step response

Normalized graph of model response to the optimized driving function is shown in fig. 2. Since usability of simple non-hysteresis model is examined, the response of the linear simulated system is strictly replicating the demanded trajectory in contrast to measured response of real piezo bender which suffers from strong hysteresis effect. The velocity deviation amounts up to 10 % of full range. The graph below shows that simple linear models are not suitable for precise modelling of piezo materials behavior. But as will be shown further, it is sufficient for need of this article.

It was shown that simple linear numeric model cannot fully simulate piezo actuator behavior. On the other hand it can be used for testing and approximate determination of controller type and parameters. It was simulated and real model verified that for the need of this application the PI controller is the most suitable. Since desired sampling frequency for real set-up was 1 kHz, the simulation parameters are to be set the same. With resonant frequency of this particular bender being approximately 2 kHz, the danger of destroying the device is not eminent since sampling frequency is way below this limit. In the other case the precautions have to be considered in order to protect the device from getting into resonance and subsequently get destroyed. It will be shown, that for this purpose the simulation with presented model is sufficient.

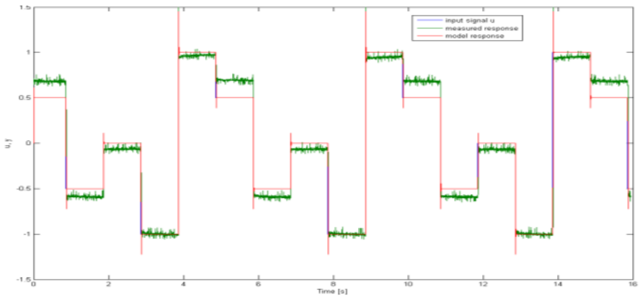

Fig. 2. Comparison of model response and real system response with hysteresis

3. Control system characteristics

As stated above the PI controller was chosen as the most appropriate structure type for the piezo bender. By combination of methods the parameters for the controller were determined and tested both on numerical model and real system. The system response for selected settings P=2, I=1400 is depicted below in figure 3.

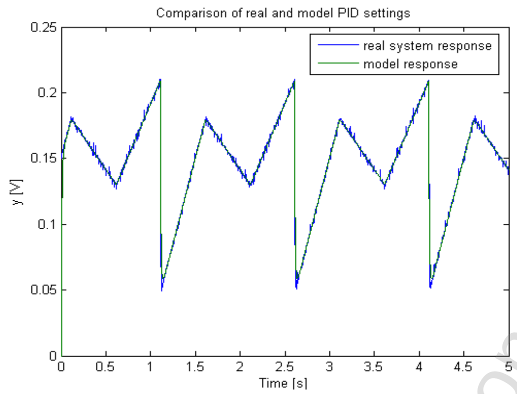

Fig. 3. Linear function response of model and real system

Due to the limited range of symbolic control variables it is necessary to use PID Anti-windup control mechanism. As a method of anti-windup the back-calculation was selected. As is shown on semi-continuous driving signal in fig. 3, the capability of precise tracking of desired trajectory of real system is very high and it corresponds with numeric model. The linear model proved to be sufficient for this kind of application.

The process of testing and identifying PI parameters was repeated for very low sampling frequency of 100 Hz. The usability of the solution was verified since for settings of P=9, I=900 very fast response of 1-2 samples (10-20 ms) was received without any undesirable overlap or oscillations after non-continuous test jumps.

Also the robustness against external errors was tested for all of mentioned settings. Figure 4 contains depiction of 100 Hz, P=9, I=900 set-up reaction to external force. Designed regulator eliminated external influence up to the saturation of ±30 V system limits.

As it is visible in fig. 4 fast harmonic error, determined by the sampling frequency, will shortly influence the position deviation in the limits of 10 – 20 ms system reaction time. In case of 1 kHz sampling frequency is significantly eliminated.

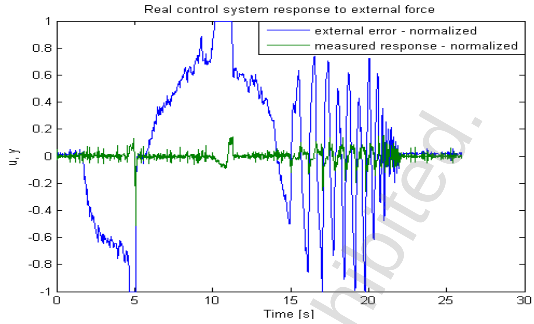

Fig. 4. Real control system response to external error (100 Hz, P=9, I=900 set-up)

4. Remarks and conclusion

Piezoelectric bender actuator was analyzed; its simple model was created and compared with reality. The usability of this numerical model was discussed and subsequently the model was used for controller parameters setting.

It was presented that even with low sampling frequency of the feedback circuit it is possible to build a robust control system without the actual need of advanced hysteresis modelling of the piezoelectric material properties.

Although it is recommended to use a different type of displacement feedback device, ideally an optical displacement sensor, it was shown that controllability of piezo bender is possible even with significantly distorted feedback signal. This may be important in applications where contactless optical measuring is not possible or advisable.

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