THE CONTROLLABILITY AND BEHAVIOR ANALYSIS
OF PIEZOELECTRIC BENDING ACTUATOR ASSEMBLY

Michal Kaśparek1, Piotr Owczarek2, Paweł Bachman3
1Technical University in Liberec, Faculty of Mechanical Engineering, Department of Applied Cybernetics, 2Poznan University of Technology, Institute of Mechanical Engineering, 3University of Zielona Góra, Faculty of Mechanical Engineering, Department of Security of Technical Systems

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

1. 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.

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:

\[
x = \frac{0.09134}{1.336e^{-9} \cdot s^2 + 2.004e^{-6} \cdot s + 0.001753} + 1
\]

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.

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.

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.

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 strongly influence the position deviation in the limits of 10 – 20 ms system reaction time. In case of 1 kHz sampling frequency is significantly eliminated.

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.

References


Ing. Michal Kasparek, DI.

Author is a member of Department of Applied Cybernetics of Faculty of Mechanical Engineering, Technical University in Liberec. In his work he focuses on signal processing, control systems, noise and vibration damping and acoustic systems analysis.

M.Sc. Piotr Owczarek

e-mail: piotr.owczarek@put.poznan.pl

Ph.D. student and assistant in Division of Mechatronics Devices in Poznan University of Technology. He graduated from electrical engineering, robotics and control engineering in 2011. His research interests include modern methods of digital image processing, artificial intelligence methods, design of electronic and mechatronic devices, mobile robots, industrial controllers.

Ph.D. Paweł Bachman

e-mail: P.Bachman@ibup.uz.zgora.pl

Assistant professor at the Faculty of Mechanical Engineering in University of Zielona Gora. Interests: mechatronic devices, microprocessor controllers and electro-hydraulic servo drives.

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