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Application of geometry based hysteresis modelling in compensation of hysteresis of piezo bender actuator

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ABSTRACT

This paper presents results of studies of an application of a new method of piezo bender actuators modelling. A special hysteresis simulation model was developed and is presented. The model is based on a geometrical deformation of main hysteresis loop. The piezoelectric effect is described and the history of the hysteresis modelling is briefly reviewed. Firstly, a simple model for main loop modelling is proposed. Then, a geometrical description of the non-saturated hysteresis is presented and its modelling method is introduced. The modelling makes use of the function describing the geometrical shape of the two hysteresis main curves, which can be defined theoretically or obtained by measurement. These main curves are stored in the memory and transformed geometrically in order to obtain the minor curves. Such model was prepared in the Matlab–Simulink software, but can be easily implemented using any programming language and applied in an on-line controller. In comparison to the other known simulation methods, the one presented in the paper is easy to understand, and uses simple arithmetical equations, allowing to quickly obtain the inversed model of hysteresis. The inversed model was further used for compensation of a non-saturated hysteresis of the piezo bender actuator and results have also been presented in the paper.

1. Introduction

1.1. Basics of piezo bending actuators

Invention of the piezoelectric bimorphs (or benders) dates back to the early 1930s [1]. Series and parallel configurations for driving a piezo bimorph benders were patented by Sawyer in 1936 (US patent 1995257-A). Piezoelectric bimorphs make use of mechanical deformation of electro-active piezoceramics under electrical field exposure. They are a special type of smart structures and they have been widely used due to high maximum frequency, which reaches 2 kHz, high positioning accuracy and displacement within a range of several millimetres (plate benders: PL112.10 [2] or CMBP 03 [3]). Piezo bending actuators have been used in many applications of small robotics, such as micro air vehicles, indoor slow fliers or legged microrobots. A bending actuator consists of multilayered piezoceramics which can either be a double-side mount or a single-end one. Three different configurations of piezoelectric benders are most commonly used: the heterogeneous bimorph, also known as monomorph or unimorph, which consists of one piezoelectric and one passive layer; the triple-

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layer bender, consisting of two piezoelectric layers acting in opposite manner, and a mechanically relevant passive layer in between; and finally the bimorph of the same configuration as the second one but without the intermediate layer.

A simple bimorph is made out of two laminated piezoelectric layers of the same thickness (Fig. 1). This element produces curvature when one layer expands while the other layer contracts. Depending on the electrode structure and poling direction P, the piezo bimorphs are classified as parallel or series. The first ones are made of two layers of the same direction of polarisation P (Fig. 1a). An intermediate electrode allows using electric signals of opposite directions in the top and bottom layers. In the series piezo elements, the orientation of the layers' polarisation is opposite (Fig. 1b). Their electrodes are connected only to the top and bottom surfaces. Exposure of these two layers to an electric field causes one layer to expand and the other to contract, which results in a bending deformation. For the same motion, a 2-layer element needs only half the voltage required for series operation, but has four times the capacitance.

Piezoelectric bending actuators have become more and more popular because of their high output displacement and low supply voltage [2,3] in comparison to stack actuators. These actuators are an attractive option for driving micro devices, which require displacements of about several millimetres and forces of only about several newtons. As a result, it is possible to use them in a wide variety of high-accuracy positioning units, e.g. in precise electrohydraulic servo valves instead of a torque motor [4].

In the last years several researches have been undertaken in order to improve the behaviours of piezo actuators. For example, Bansevicius et al. [5] described new studies of design of triple layer piezoelectric bending actuators. These actuators were analysed, modelled and tested experimentally. The investigations have shown that the proposed benders can be used to improve mechanical reliability. Gosiewski et al. [6] investigated modelling of a smart beam which consists of a steel beam with two piezoelectric stripes bonded to its surface. One strip works as a sensor, and the other as an actuator. The dynamics of the proposed beam was investigated for different locations of the strips along the beam, using both an analytical solution and the modelling technique.

A popular approach used for compensation of the piezoelectric actuators hysteresis is to linearise them by including the inverse model of the actuator into controller before the real actuator [7]. Song et al. [8] proposed use of a feedforward model in the controller to improve performance of the control system. However, performance of the proposed compensation method is also determined by accuracy of the inverse model. Therefore, in this method it is critical to obtain an inverse model of hysteresis as accurate as possible.

In this paper, the parallel bimorph (bending) actuator is considered. Its main advantage is its relatively large displacement (about 1 mm) and low supply voltage (<200 V), but such a transducer only produces forces up to several newtons. In positioning applications the piezo actuator suffers from non-linarites such as: strongly nonlinear course of the voltage-dependent displacement curve; hysteresis between the input voltage and the resulting displacements; a creep, which is a change in the displacement over time with an unchanged drive voltage. All of them, decrease the transducer positioning accuracy, but the most influential is hysteresis between the input voltage and the resulting displacements. That is why its compensation is necessary in ultra-precision positioning systems. The simple compensation methods utilise a closed-loop control system with a displacement feedback sensor and with different controllers, such as Proportional-Integrative-Derivative (PID), H-infinity or Model Predictive Sliding Mode Control (MPSMC) [9]. Unfortunately, in many cases this solution cannot be implemented because there is no space for the sensor assembly. For example, when bending actuator is used in a pneumatic or hydraulic valve, there is no place for both the displacement sensor and additional wires for

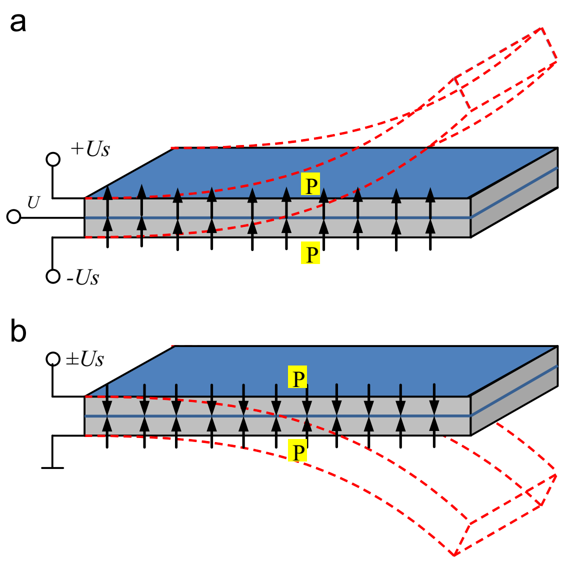

Fig. 1. Electrical configurations of piezoelectric bimorphs: (a) parallel, (b) series (P-poling).