



Parameter identification and hysteresis compensation of embedded piezoelectric stack actuators

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ABSTRACT

A novel method for the identification of embedded piezoelectric stack actuator parameters in combination with a real-time capable hysteresis compensation measure is presented. The presented algorithms are based on the Maxwell resistive capacitor model and are particularly useful for the identification of piezoelectric actuators embedded in a high-precision micropositioning system where the disassembly of the complete system for separate actuator identification is not recommended or not possible. The parameter identification can be performed in a fully automated way and enables the adaptation of the compensation routine to the changed circumstances (temperature difference, wearing of actuators) as well. The hysteresis compensation method proposed here does not require significant CPU or memory resources. It can be implemented as an additional task on the already existing controller or a low-budget FPGA. As an example, the proposed method was validated experimentally by the parameter identification and hysteresis compensation of the piezoelectric actuators incorporated in a commercially available hybrid micropositioning system. The achieved experimental results are in very good agreement with the theoretical ones.

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1. Introduction

Many industry applications like semiconductor production and optical inspection systems demand positioning systems capable to follow trajectory paths in the range of several centimetres, featuring at the same time a nanometre-range precision. Neither pure piezoelectric systems nor standard positioning devices with electric motor and spindle are capable to meet such requirements.

Recently, several approaches have been presented in an attempt to overcome these problems. Chiang et al. [1] developed a hybrid actuator system with cascaded mechanical connection of a hydraulic and piezoelectric actuator. Chen and Dwang [2] presented an approach with a ball screw drive mechanism featuring a piezoelectric nut for active ball screw preload and fine motion control. An improved nanopositioning system based on a similar approach was presented in [3]. Liu et al. [4] and Glöck [5] proposed the cascaded mechanical connection of a DC-drive and a piezoelectric actuator (PEA) for use in positioning systems with one or more degrees of freedom.

With a hybrid micropositioning system, operation ranges larger than 100 mm with positioning velocities of 100 mm/s can be

achieved, enabling at the same time nanometre-range positioning precision. The Hybrid Micropositioning Stage from Physik Instrumente [5], shown in Fig. 1, is a typical example of such an actuator. It consists of a DC-drive (M) connected to a spindle of inertia J_M , a gearbox (G) with the reduction ratio i_{rt} , and two moving masses (m_1, m_2) with a pair of identical piezoelectric actuators (P) in between. The DC-drive (with angular position ε_M) moves the coupled masses m_1 and m_2 together, whereas the PEA performs additional movement of m_2 related to m_1 . Each PEA is mounted in parallel with a spring c . The main function of the springs is to pre-stress the PEA, enabling thus a symmetrical bipolar voltage operation range. The piezoelectric actuators are excited by the same voltage v_p . The object O (object to be positioned, not shown in Fig. 1) is fixed to m_2 , and its linear position s_2 is detected by a high-precision incremental sensor. An equivalent schematic representation of the system is given in Fig. 2. The piezoelectric actuators and springs are represented by a single equivalent actuator, connected in parallel to a single equivalent spring. Fig. 2 shows the initial length of the piezoelectric actuators, denoted with l_p , and their displacements x .

For the design of an advanced control law capable to tap the full potential of such systems, real-time compensation of plant nonlinearities – like the hysteresis of the PEA – is of a key importance. This imposes the need for an accurate PEA model which can be parameterized in a straightforward way and is suitable for real-time implementation.

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