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Hybrid charge control for stick–slip piezoelectric actuators

Martin Špiller [1], Zdeněk Hurák *,[2]

Faculty of Electrical Engineering, Czech Technical University in Prague, Karlovo namesti 13/E, 12135 Prague, Czech Republic

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ABSTRACT

The article describes an analog electronic circuit for driving stick–slip piezoelectric linear actuators. The task for the amplifier is to provide a high-voltage asymmetric sawtooth-like signal and feed it into a capacitive load. Generation of excessive heat must be avoided while maximizing the slew rate. In order to guarantee a steady translation, the hysteretic behaviour of the piezoelectric material must be compensated. Combination of a charge control scheme with switching is proposed as an efficient solution. Laboratory experiments confirm the superiority of this tailored solution over other existing techniques based on versatile linear voltage amplifiers.

1. Introduction

1.1. Motivation, goals

Stick–slip piezoelectric micro-actuators represent an elegant way to overcome the limitations imposed by the rather small strain of piezoelectric materials. Inheriting the spirit of stepping motors, they can offer a practically unlimited range of motion with a sub-micron resolution. The goal of the presented research is to develop an analog electronic driver for a stick–slip piezoelectric micro-actuator. Its function consists in forming an asymmetric sawtooth-like voltage with the peak amplitude about 100 V and the switching frequency of up to a few kHz. The challenge consists in applying it to a capacitive load of a few nanofarads or tens of nanofarads. A successful design must address two issues related to this branch of micro-actuators: first, the hysteresis inherent in all piezoelectric materials must be dealt with; second, the slew rate should be maximized while keeping the power requirements modest. The capacitive character of a piezoelectric material makes these issues challenging.

1.2. Structure of the paper

In the rest of this introductory section, short introductions and surveys are given for stick–slip actuators, modeling the piezoelectric phenomenon (for the purpose of a control design) and charge control for piezoelectric actuators. The next section brings the core contribution of this paper – design of a charge amplifier combined with switching. The third section then documents some laboratory experiments with the proposed driver and compares its performance with a conventional voltage amplifier.

1.3. Stick–slip piezoelectric actuators

Stick–slip based piezoelectric manipulators have been around in the field of micropositioning for about two decades [1]. The basic idea is visualized in Fig. 1. Two or three (or more) legs made of piezoelectric ceramics such as PZT are polarized in a shear mode and topped by a sapphire half-sphere. A slowly rising voltage (rising usually above 100 V) then deforms these legs such that a slider placed freely on them is carried in a horizontal direction. Steep descending edge in the applied voltage signal causes fast deformations of the legs back to the original state whereas the slider rests at the new position because of its non-negligible inertia. Repeating this single step leads to a behavior resembling a walker. The spatial resolution is thus given by the length of one step, which is usually around a few tens up to a few hundreds of nanometers. A nice feature of stick–slip actuators is that the resolution can be further improved by controlling the displacement of the piezos continuously within a single step, the actuator is then said to work in a *scanning mode*. Comprehensive overviews can be found in a series of doctoral theses and papers produced by a micro-robotics group at EPFL, such as [2–8].

1.4. Mathematical model of piezoelectricity

The notoriously known constitutive relationship between a deformation (strain S) of a piezoelectric slab and an electric field

* Corresponding author. Tel.: +420 224357683.
E-mail address: hurak@fel.cvut.cz (Z. Hurák).

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