Chapter 1

Open Loop Force Control of Piezo–Actuated Stick–Slip Drives

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ABSTRACT

In this paper a new method to generate forces with stick-slip micro drives is described. The forces are generated if the runner of the stick-slip drive operates against an obstacle. It is shown that the generated force can be varied selectively without additional sensors and that virtually any force between zero and a limiting force given by certain parameters can be generated. For the investigated micro actuator this force is typically in the range up to hundreds of mN. For this reason, the method has the potential to expand the application fields of stick-slip positioners. After the presentation of the testbed containing the measured linear axis, measurements showing the principle and important parameters are discussed. Furthermore, it is shown that the force generation can be qualitatively simulated using state-of-the-art friction models. Finally, the results are discussed and an outlook is given.

INTRODUCTION

Stick and slip micro-drives or micro-actuators (SSA) are well-known and have been under investigation for at least two decades. One of the first SSA was presented by Pohl in 1987. It is driven by a piezoceramic tube, which operates on a slider, carrying the object of interest. With control frequencies of up to 500 Hz, a slider’s velocity of 0.2 mm/s can be reached. With the development of piezoceramics, control electronics and fabrication techniques and the rising interest on small, vacuum capable ultra-fine positioners a lot of developments came up. In 1995, Zesch presented the locomotion platform Abalone based on the stick-slip principle (Zesch, Buechi, Codourey, & Siegwart, 1995). It is driven by three piezoceramic stack-actuators and can move in three degrees of freedom (DOF) on a working surface. This allows a flexible positioning of specimen.
e.g. for light- and electron-based microscopes. Other research groups came up with similar approaches. The Piezowalker is a design close to that of Zesch, but with a driven rod in the middle of the structure (Mariotto, D’Angelo, & Shvets, 1999). The group around Breguet and Bergander presented several mobile micro robots for different applications (Bergander, Driesen, Varidel, & Breguet, 2003a; Bergander, Driesen, Varidel, & Breguet, 2003b; Breguet, 1998). Munassypov et al. (1996) presented a mobile platform driven by bending piezoceramic tubes (Munassypov, Grossmann, Magnussen, & Fatikow, 1996). Each of the three tubes can be displaced in two DOF similar to a leg. Thus, motions in three DOF are possible. Another mobile robot driven by piezoceramic tubes is the Nanowalker (Martel et al., 2001). It is designed in such a way that the miniaturized control electronics including an energy source is carried by the robot aiming towards an untethered mobile nanohandling robot. However, several problems such as the influence of the robot’s mass on the working principle, wear caused by friction or overheating electronics prevented extensive applications.

It can be noted that the most important advantages of SSAs are their simple design (a SSA rarely consists of more than a handful of mechanical parts), the small piezoelectric coefficient which allows positioning in the nanometer scale, the stick-slip working principle itself which combines fine positioning with large travels, and the high potential of miniaturization. Nevertheless, the function of SSAs is intimately connected with friction characteristics and therefore, results such as the performed step lengths can vary. For this reason, measurement and control of the generated displacements is necessary in most cases. Today, SSAs are established in research as well as in the commercial field. Linear and rotary positioners are commercially available, e.g. by the companies SmarAct, Kleindiek Nanotechnik, Kloccke Nanotechnik or Attocube. Applications performed with these actuators can be found in (Rabenorosoa, Clévy, Lutz, Bargiel, & Gorecki, 2009; Peng et al., 2004; Noyong, Blech, Rosenberger, Kloccke, & Simon, 2007; Meyer, Sqaelli, Lorenz, & Karrai, 2005; Vogel, Stein, Pettersson, & Karrai, 2001). Since early 2010, Imina Technologies, a spin-up of the Ecole Polytechnique Fédérale de Lausanne, Switzerland, firstly offers mobile nanohandling robots for nanomanipulation applications. The robots are the result of several research projects. Descriptions of the robots can be found in (Bergander et al., 2004; Canales et al., 2008). Commercial applications of the robots have not been documented yet. In research, mobile, multi-DOF nanohandling robots are still in the focus of investigation in contrast to single-DOF actuators. An almost all-embracing classification and description of mobile nanohandling robots can be found in Driesen (2008). Appreciable examples were published by the group of Fatikow (Edeler, 2008; Jasper & Edeler, 2008). The center of gravity is on the automation of the robots as part of nanohandling scenarios. The mobile nanohandling robots offer a wide velocity range combined with high resolution and good open- and closed-loop control characteristics. Another approach of mobile robots using the stick-slip principle was presented by Das, Zhang, Popa, and Stephanou (2007) (Murthy, Das, & Popa, 2008; Murthy & Popa, 2009). A stick and slip crawling motion with electro-thermal actuators is used to drive mobile robots with dimensions in the sub-mm scale. General examples for the application of SSAs in research are cell manipulation (Trüper, Kortschack, Jähnisch, Hülsen, & Fatikow, 2004; Hagemann, Krohs, & Fatikow, 2007; Brufau et al., 2005), the handling of carbon-nano-tubes (Eichhorn, Carlson, Andersen, Fatikow, & Bøggild, 2007; Eichhorn et al., 2009) or applications in material science (Breguet, Driesen, Kaegi, & Cimprich, 2007; Fatikow et al., 2007). It can be concluded that SSAs are exclusively used to position objects in present literature. This is in contrast to investigations concerning the generated forces of piezo-driven actuators not using the stick-slip.
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