Chapter 2
Dynamic Characteristics of Tiny Ultrasonic Linear Actuators

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ABSTRACT
Tiny ultrasonic linear actuators (TULAs) are used in many industrial applications and a full characterization of their dynamic behavior is needed. This paper presents a detailed theoretical-experimental study of TULAs. The general structure and operation principle of TULAs are introduced. The actuator dynamics is then described using a simple piezoelectric model. In practice, TULAs are most often used as actuators for positioning mechanisms. The proposed model includes electromechanical relations which offer designers a broad range of possibilities for precise positioning and reliable model-based control. TULAs are experimentally investigated to determine the conditions that allow an optimal performance.

INTRODUCTION
Electromagnetic motors were invented more than a hundred years ago and yet, they still dominate the industry: DC motors, servomotors, and stepping motors are traditionally used to achieve rotational motion and, through ball-screw mechanisms, linear motion. Even though the indisputable popularity and advantages of electromagnetic actuators, it is well-known that they present serious drawbacks at the meso/micro scale: upon dimension reduction 1) system complexity increases significantly and 2) energy efficiency decreases considerably. Without a drastic improvement in magnetic or superconducting materials, electromagnetic technology seems limited to solve these problems.

Applications for micro/miniature actuators abound in diverse fields such as medicine, biotechnology, electronics, robotics, aeronautics, and the automotive industry. Solutions have been just as diverse with designs using traditional actuation technologies such as electromagnetic, pneumatics,
and hydraulics, as well as smart materials such as piezoelectric ceramics, shape memory alloys (SMAs), polymer gels, and electrorheological (ER) fluids.

In fact, the interest on smart materials has grown in the last decades due to their unique properties. This class of materials has the ability of changing its shape, size, stiffness, among other properties, through the imposition of electrical, electromagnetic, temperature or stress fields.

A new class of motors using high power ultrasonic energy is gaining widespread attention. In particular, ultrasonic motors made with piezoelectric ceramics have become interesting actuators in the mini-motor field.

An ultrasonic motor is a type of electric motor powered by the ultrasonic vibration of a piezoelectric component, the stator, placed against another component, the slider. This concept dates to the 1970s when IBM successfully implemented the first working prototype (Barth, 1973) and the former USSR presented some mechanisms based on the same principle (Gromakovskii, 1978). Because of difficulty in maintaining a constant vibration amplitude with temperature rise, wear, and tear, ultrasonic motors were not of much practical use at that time. During the 80s, the semiconductor industry began to request much more precise, sophisticated, and free from magnetic field noise actuators. This accelerated the development of ultrasonic motors (Uchino, 1998). Sashida and Kenjo (1993) significantly improved the previous designs and were the first to use the system’s resonance to create vibrations. They earned the ultrasonic motor name by operating at frequencies in the ultrasonic range (>20 kHz) (Sashida & Kenjo, 1993).

Some advantages of ultrasonic motors include: compact size, simple structure, high torque densities at low speed, fast response, self-locking, long-travel intermittence motion, excellent controllability of starting/stopping/reversing, and efficiency insensitive to size. Two main drawbacks are the necessity for a high frequency power supply and less durability due to frictional drive (Uchino, 1997).

Tiny ultrasonic linear actuators (TULAs) are devices commonly used for zooming or auto-focusing functions in imaging systems of personal computers, mobile phones, digital cameras, video equipment, PDAs, etc. Recently, their real potential is just beginning to be exploited in applications as diverse as tactile displays for the blind (Hernandez, 2009), medical instruments (Suzuki, 2007), MEMS (Higuchi, 2005), toys (Bansevicius & Blechertas, 2006), precision watches (Iino, 2000), industrial robots (Toyama & Kobayashi, 1996), and micro-robotics (Park, 2008; Yamano & Maeno, 2005). Due to their compact size, TULAs will be undoubtedly in large demand over the next decade mostly in the consumer electronics market.

To fully exploit the performance of these actuators, a characterization of their dynamics is essential. This paper presents a comprehensive review of the main characteristics of TULA piezo-motors and intends to serve as a guide for simple/fast/reliable numerical analysis and experimental evaluation of their behavior. The rest of the paper is organized as follows: the general structure and operation principle of TULAs are first introduced. Then, a simple electromechanical model to simulate its behavior is proposed. A series of experimental results performed on a TULA prototype are presented to illustrate their actuating properties. Finally, the paper concludes summarizing the main concepts and results.

**STRUCTURE AND OPERATION PRINCIPLE OF TULAS**

TULAs simply consist of a shaft, a mobile element or slider, and a piezoelectric ceramic disk (Figure 1(a)). They can be found from several manufacturers in the 3-15 mm range which satisfies most of the portable consumer electronic motor demands. Figure 1(b) shows for example, one of the smallest TULAs commercially available.
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