Mission Critical Motion Control™

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Piezoelectric Actuation Mechanisms: An Introduction

Using piezo-actuators requires an understanding of actuator mechanical and electrical performance issues. Understanding the basic operating concepts behind piezo-actuators may also be beneficial to controlling and operating the piezo-actuators. The following information on piezo-actuator design and performance issues can be helpful when comparing piezoelectric-based actuators to more conventional electromagnetic actuators (solenoids, motors, voice-coils) and other "induced strain actuator" materials such as electrostrictive ceramic, magnetostrictive, and shape memory alloys.

Applications for Piezo-Actuators

Actuators based on piezoelectric ceramic material prime movers (or piezo-actuators) are finding broad acceptance in applications where precision motion and/or high frequency operation is required. Piezo-actuators can produce smooth continuous motion with resolution levels at the nanometer and sub-nanometer level. This property makes them useful in precision positioning and scanning systems. The very fast response times, wide operating bandwidth, and high specific force may be beneficial for applications in fluid valve control, optical scanning, vibration isolation, and precision machining.

Using the Piezoelectric Effect to Generate Motion and Force

Producing Displacement: DSM uses the term "piezo-actuator" for actuator or motion generating devices that use electro-expansive ceramic materials such as lead zirconate titanate (PZT), as the prime mover. Piezoelectric materials exhibit an effect whereby they expand or contract in the presence of an applied electric field. This "induced strain" or change in length occurs as electrical dipoles in the material rotate to align with an orientation that more closely aligns with the direction of the applied electric field. The change in length is generally proportional to the field strength as applied via the device actuation voltage. A typical value for length change might be 0.1 percent of the total material length in the direction of the applied field. For example, when actuated, a 1 mm thick layer of PZT will increase in thickness by one micron. A monolithic stack of PZT layers and electrodes (called a PZT stack) is most often used in DSM's piezo-actuators. PZT stacks expand in the column direction as represented in Figure 1.

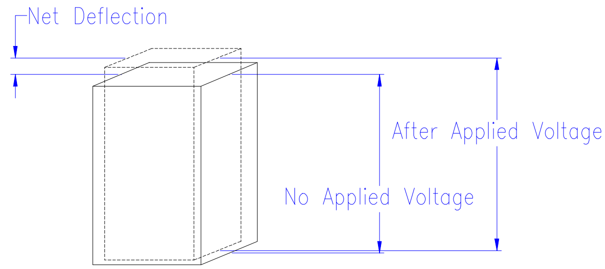

Figure 1 – Example of PZT stack expansion

PZT material fabricators supply their materials in the stack geometry to best leverage the piezoelectric effect at low voltages. A stack consists of many thin layers of PZT ceramic laminated together and electrically connected in parallel. PZT stacks come in various sizes and shapes and can be combined to produce extended motion. Useful expansions can be achieved at voltage levels as low as 10 volts, although many fabricators design their low voltage stacks for operation up to 150 volts. PZT stacks are typically available in circular or rectangular cross-sections from 1 mm to 14 mm across and in lengths as small as a few millimeters. Other form factors for PZT in actuator applications include tubes and thin patches or strips bonded to one or both sides of a substrate material.

DSM has developed a number of actuators that use mechanical amplification to enhance the small levels of expansion found in PZT materials (see "Amplification Mechanisms" Techbrief). These actuator mechanisms leverage the high force and small stroke of PZT materials to create many times greater stroke levels. Figures 2, 3, 4, and 5 represent some of the basic piezo-actuator amplification concepts for PZT stacks and thin patches.

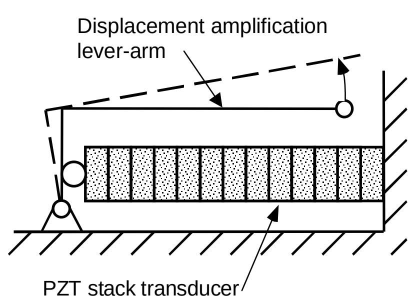

Figure 2 – Simple lever-arm mechanism

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Figure 3 – DSM LPA-100 piezo-actuator uses a simple lever-arm mechanical amplification. (PZT stack is green - output is in vertical direction)

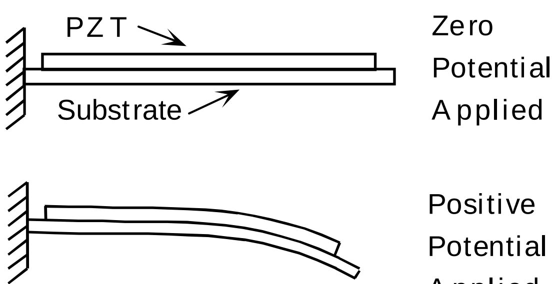

Figure 4 – PZT uni-morph patch amplification

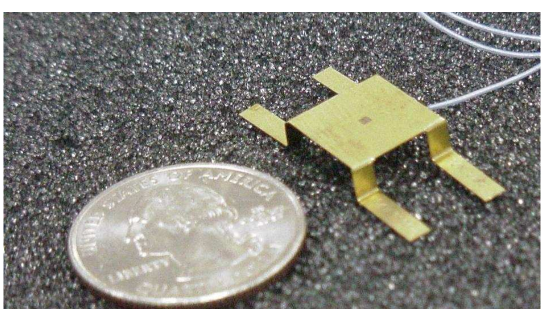

Figure 5 - A miniature piezo actuator for a 70 um displacement switching application uses a uni-morph amplification concept.

Producing Force: PZT stacks are displacement-generating devices. They expand proportionally to the applied electric field or actuation voltage. Maximum motion or expansion of the PZT occurs at maximum actuation voltage. When an external load resists the motion of the PZT expansion, the PZT stacks apply a force that is a function of the stiffness of the external load. The PZT stacks can generate a very high level of pressure against an external load if the stiffness of the external load is high enough to prevent expansion of the PZT. Typical blocked pressure levels are 5 to 7 ksi (34 to 48 MPa).

Strengths of Piezo-Actuators

Given the relatively small displacement that a PZT stack can develop, piezo actuators have unique design considerations. For example, piezo-actuators excel in precision positioning applications where small, high-force moves are desirable. When fabricating, measuring, or testing extremely small structures or features, piezo-actuators can provide very smooth and continuous motion over a range of a few microns to a few millimeters. With proper system design, piezo-actuators hold the potential for high speed operation. Generally, the response time of a piezo-stack is limited by the speed of sound in the material. Therefore, natural frequency of a PZT stack may be several kiloHertz. Even with the added mass and lower stiffness of an amplification mechanism, the natural frequency of an amplified piezo-actuator may be a few kiloHertz.

Additionally, when designed and constructed properly, piezo-actuators can exhibit the following strengths.

- solid-state construction with zero backlash, stiction, or cogging
- low or zero power position hold capability
- very high frequency response (bandwidth)
- very high force per unit area (force and stroke directly scales with size)
- little or no outgassing or particle generation as flexure based designs have little or no friction and require no lubrication
- relatively low heat generation
- highly scaleable and reliable

Summary

DSM's piezo-actuators harness the small precise amount of expansion generated by the piezoelectric effect to produce a wide range of actuator solutions. With proper design, piezo-actuators have performance attributes and properties that can be valuable in precision positioning, vibration control, and scanning applications. Smooth, precise motion from the sub-nanometer to multiple-millimeter level is possible with a variety of solid-state actuation/amplification mechanisms.