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Piezoelectric Actuation Mechanisms: Design Challenges With Piezo-Actuators

Developing piezo-actuators that feature precision motion capabilities presents an opportunity for creative solid-state mechanism design. DSM has developed strategies to deal with the challenge of short strokes and very high forces inherent to piezoelectric materials. Piezo-actuator design must account for the following issues.

- Reactive energy
- Hysteresis, creep, and temperature instability
- Spring effects - available force is not constant, but dependent on position
- Energy losses from compliance in the system

Reactive Energy: Driving a piezo-actuator requires sourcing sufficient current from the driver (programmable power supply or amplifier) to produce the desired electrical field or voltage level in the PZT stack. Because PZT stacks have relatively high capacitance, only a small amount of the energy delivered by the driver is used to move the load. The majority of the current applied is in the form of reactive power. Thus, the driving electronics must be able to move a relatively large amount of charge in and out of the PZT stack. This is slightly analogous to a four-quadrant drive for a DC motor with the added complication that the load is capacitive rather than resistive. In short, the drive electronics for a piezo-actuator are specialized for driving capacitive loads.

Hysteresis, Creep, Temperature Instability: Dipole hysteresis in piezoelectric actuator displacement manifests itself as a difference in displacement path in the forward stroke compared to the return stroke. Therefore, the correlation between voltage and strain in piezoelectric materials is typically not highly linear. Open-loop hysteresis is generally around 10 to 15% of full scale, depending upon the particular piezo material. The output of the piezo-actuator in a standard displacement graph reflects this variation in forward versus return path displacement (Figure 1).

To compensate for the change in position, one must drive the piezo-actuator to a slightly different voltage in the return move to get back to the same starting position. The value of the stroke hysteresis is a percentage of the entire commanded stroke. For example, a 50 micron move would produce a hysteresis level of 5 to 7.5 microns.

Since PZT stack expansion occurs when electrical dipoles in the material rotate, the expansion is susceptible to temperature, time, and material resistance effects. Changes in temperature cause dipole creep or variations in dipole mobility. Dwelling at a specific dipole orientation for a period of time manifests itself as slight mechanical creep or drift in the PZT displacement. Drift or creep of 1 to 3% might be manifested, therefore, DSM recommends the use of displacement feedback to achieve the very fine resolution possible in piezo-actuators.

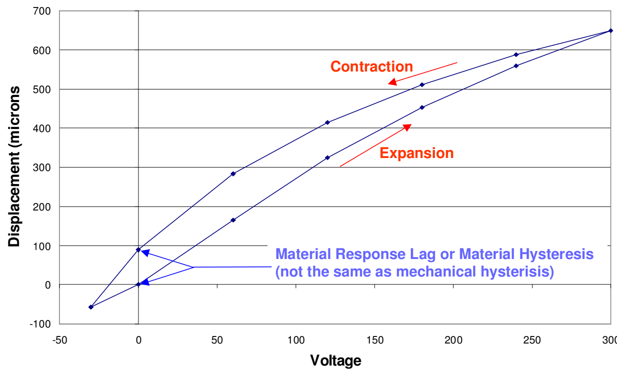

Figure 1 - Voltage-Displacement curve for one of DSM's amplified piezo actuators in open loop motion. Note the hysteresis between the expansion and contraction paths.

Spring Effects: A piezo-actuator acts like a spring; the force it develops is not constant over its range of motion as might be the case for a linear motor or air cylinder device. The force available from a piezo-actuator progressively decreases as it extends. It is important to consider the stiffness of the actuator and the forces pushing against it to assure that it will operate correctly. Because the PZT stack is a displacement generating device and only develops force as its expansion is resisted, the amount of displacement and remaining pushing force are dependent on the stiffness of the applied load. DSM specializes in high stiffness actuators that can deliver long stroke/high force performance in compact sizes.

Energy Losses from Compliance: Since piezo-actuators produce small levels of displacement, any mechanical slop, play or backlash in the actuator system or in the mechanical connecting elements reduces the available work. As a result, DSM recommends working with a competent actuator designer to develop the appropriate connections and mountings systems incorporating piezo-actuators.