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Piezoelectric Actuation Mechanisms: Flextensional Piezo-Actuator Operation

Solid State Kinematic Elements

The active element in DSM's flextensional piezoelectric actuator (FPA) architecture is the "PZT stack" in the center of the frame. As the applied voltage on the piezo stack is increased, the PZT stack expands (see DSM App Note - An Introduction to Piezo-Actuation). DSM's FPA mechanism design mechanically amplifies this expansion (in the long dimension of the piezo stack) through the solid-state kinematic elements in the metal frame wrapped around the PZT stack.

The kinematic elements in the amplification frame include links or blocks (thicker metal sections) connected by thin metal webs called "flexures." The flexures act like frictionless hinges. They are designed to flex within their material fatigue stress limit for the given stroke capability of the actuator. For example, in the picture of the FPA-80E actuator below, a simple yellow line is traced through the flexures of the top arms of the actuator. As the PZT stack expands and pushes on the actuator's end blocks along the line of action indicated by the white arrow, this line straightens a small amount to produce the 80 microns of amplified motion in the direction indicated by the black arrow.

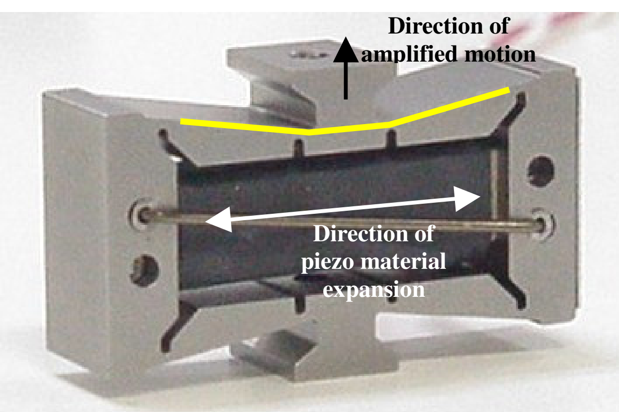

Figure 1 - PZT stack expansion in FPA-80E

Contraction vs. Expansion in Piezo-Actuators

The FPA-80E is designed as an "expansion" or "push" actuator. As the actuation voltage applied to the PZT stack increases, the actuator assembly expands outward. Over the full rated voltage range of the FPA-80E, the actuator typically achieves a nominal displacement range of 80-90 microns. This level of motion results from the amplification of the piezo stack's output motion of approximately 20 microns. The PZT material can also be driven to a small negative voltage. Under a negative voltage, the piezo material actually contracts (its length becomes shorter than at the zero voltage condition). The normally expanding piezo-actuator retracts when a negative voltage is applied.

The results of a finite element model of an FPA-100E show the exaggerated motion of the piezoelectric actuation. Figure 2 shows the results of a displacement analysis of the FPA-100E scaled by a factor of 20.

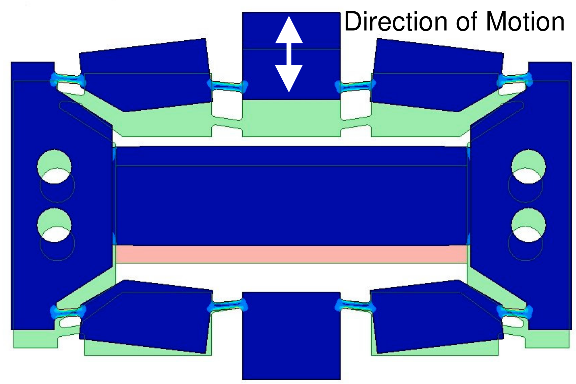

Figure 2 - Exaggerated shape of actuated FPA-100E (dark blue) superimposed over original, non-actuated shape of FPA-100E (light green) indicates the actuation direction.

The spring wire that runs across the actuator frame on both sides applies a preload that keeps the piezo ceramic in compression. The preload allows the actuator to function in contraction and expansion even when the dominant motion of the PZT stack causes expansion. The spring preload works to restore the actuator frame to its original position. When voltage on the piezo is reduced, the piezo contracts. The spring preload pulls the end blocks of the amplification frame towards one another, causing the actuator output to contract.

If an application requires a piezo-actuator with the dominant motion in a pulling/contracting mode, reversing the kinematic design of actuator causes the output points of the frame to contract as the piezo expands. The picture of DSM's FPA-1100C in Figure 3 shows the imaginary yellow line connecting

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through the flexures that flattens out as the piezo material expands.

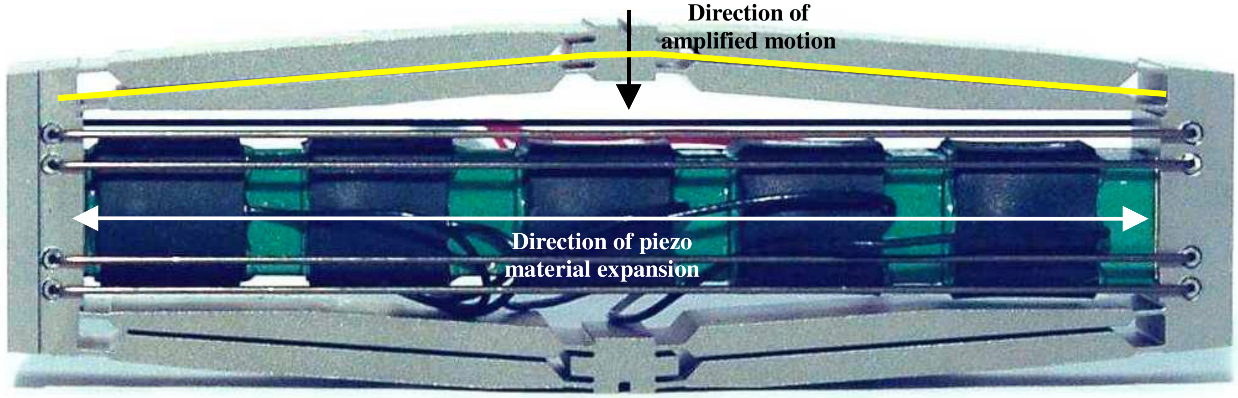

Figure 3 – FPA-1100-C showing the direction of piezo material expansion and direction of amplified motion

The comparison of the kinematic configurations of the FPA-80E and the FPA-1100C shows how the expansion of the piezo material can be used to create either an expansion/pushing (i.e., FPA-80E) action or a contracting/pulling (i.e., FPA-1100C) action. In both cases, the spring preload enables bi-directional motion as the piezo expands and contracts under a changing applied actuation voltage.

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. The Flextensional Piezoelectric Actuator FPA design represents a compact, high-stiffness means of producing highly-amplified piezoelectric-controlled motion. DSM also produces a line of Leveraged Piezoelectric Actuators which are based on solid-state kinematic lever mechanisms and generally provide a higher dynamic bandwidth than the FPA series. 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 mechanisms.