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dsm Mission Critical Motion Control™

Application Note: Driving a Spring Load with a Piezoelectric Actuator

When a piezo-actuator (whether amplified or non-amplified) is actuated against a spring load, it converts electrical energy into both motion and force. This force will vary according to the amount of expansion/contraction achieved by the piezo-actuator under the applied electrical field. When activated with an applied electric field, the piezo-actuator moves against the spring load until it reaches a force balance condition. If at this point the spring load were to be removed, the stored potential energy within the piezo-actuator would be converted completely into additional motion. Therefore, when working against a spring load, the amount of displacement that the piezo-actuator can produce in the spring load is less than the piezo-actuator's free zero-load displacement. The amount of displacement that the spring can be compressed or stretched is a function of the spring stiffness and the piezo-actuator stiffness.

The following nomenclature will be used in this discussion:

Constants

k_{spr} : stiffness or spring constant of the applied spring load

k_{pzt} : stiffness or spring constant of the piezo-actuator

$\delta_{pzt,\max}$: maximum displacement produced by the piezo-actuator with no load

$F_{\max}$: maximum force capacity produced by the piezo-actuator when k_{spr} is infinite

Variables

δ_{pzt} : displacement produced by the piezo-actuator under the applied electric field

F_{pzt} : force capacity produced by the piezo-actuator as it moves against a spring load

Piezo-actuators have an inverse, linear relationship between their force capacity (for pushing against a spring-type load) and their displacement. At zero displacement, an actuator has maximum force capacity ($F_{\max}$). At maximum displacement ($\delta_{pzt,\max}$) under the maximum applied rated voltage, the force capacity is zero. Similarly, when the stiffness of the spring load (k_{spr}) is zero, the piezo-actuator is able to achieve $\delta_{pzt,\max}$. When k_{spr} is infinite, the piezo-actuator is not able to move against the applied spring load and instead produces its maximum force capacity $F_{\max}$ against that load under the maximum rated voltage condition. The maximum force capacity $F_{\max}$ can be approximated by the product of $\delta_{pzt,\max}$ and the piezo-actuator's stiffness k_{pzt}.

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One calculates the amount of stroke that the piezo-actuator can apply to the spring load using the following equations:

Equations

The linear force-displacement relationship for a piezo-actuator pushing against a spring load is defined as

$$(1)\quad \delta_{pzt} = \delta_{pzt,\max} - \frac{\delta_{pzt,\max}}{F_{\max}} F_{pzt} \quad \text{or} \quad F_{pzt} = F_{\max}\left(1 - \frac{\delta_{pzt}}{\delta_{pzt,\max}}\right)$$

where δ_{pzt} is the deflection of the piezo-actuator and F_{pzt} is the corresponding force capacity that can be generated by the piezo-actuator at that deflection

The force-displacement relationship of the spring load is defined as:

$$(2)\quad F_{spr} = \delta_{spr} k_{spr}\,.$$

Recognizing that at equilibrium the force provided by the piezo-actuator is equal in magnitude to the opposing force from the spring load, we can equate the expressions from (1) and (2):

$$(3)\quad F_{spr} = F_{pzt} = \delta_{spr} k_{spr} = F_{\max}\left(1 - \frac{\delta_{pzt}}{\delta_{pzt,\max}}\right)$$

At force equilibrium, the actuator has compressed the spring by a distance

$$(4)\quad \delta_{pzt} = \delta_{spr}$$

Substituting (4) into (3) yields

$$(5)\quad \delta_{spr} = F_{\max}\left(k_{spr} + \frac{F_{\max}}{\delta_{pzt,\max}}\right)^{-1} = \frac{F_{\max}}{k_{spr} + k_{pzt}}$$

Generally, if the spring stiffness exceeds the piezo-actuator stiffness, less than one-half of the piezo-actuator's free displacement can be applied to the external spring. If the spring stiffness equals the piezo-actuator stiffness, than exactly one-half of the piezo-actuator's free displacement can be applied to the spring. If the spring stiffness is less than the piezo-actuator stiffness, more than one-half of the piezo-actuator's free displacement can be applied to the external spring. The

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portion of the piezo-actuator's free displacement not applied to the external spring is stored in the piezo-actuator as potential energy.

Examples of a piezo-actuator driving against a spring load

FPA-100 piezo-actuator: nominal spring stiffness k_{pzt} = 1.0 N/micron; nominal blocked force $F_{\max}$ = 145 N. For reference, nominal displacement $\delta_{pzt,\max}$ = 145 microns.

Case A: spring load having a stiffness of 0.25 N/micron (25% of the FPA-100 stiffness)

Using Equation (5), we determine δ_{spr} :

δ_{spr} = 145 N / [(0.25 N/μm) + 1 N/μm] = 116 μm

Case B: spring load having a stiffness of 1.5 N/micron (150% of the FPA-100 stiffness)

Using Equation (5), we determine δ_{spr} :

δ_{spr} = 145 N / [(1.5 N/μm) + 1 N/μm] = 58 μm

Case C: spring load having a stiffness of 1.0 N/micron (equivalent to the FPA-100 stiffness)

Using Equation (5), we determine δ_{spr} :

δ_{spr} = 145 N / [(1 N/μm) + 1 N/μm] = 72.5 μm