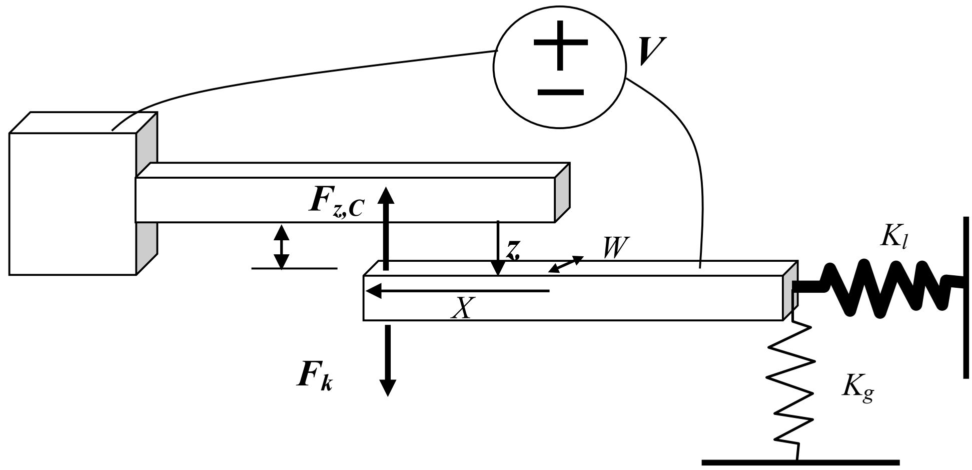
Lecture 8-3 Design Comb-drive Actuator through MCNC/MUMPS Process: II

◆ Process and operational issues

1. Pull-in effect for Gap-closing actuator

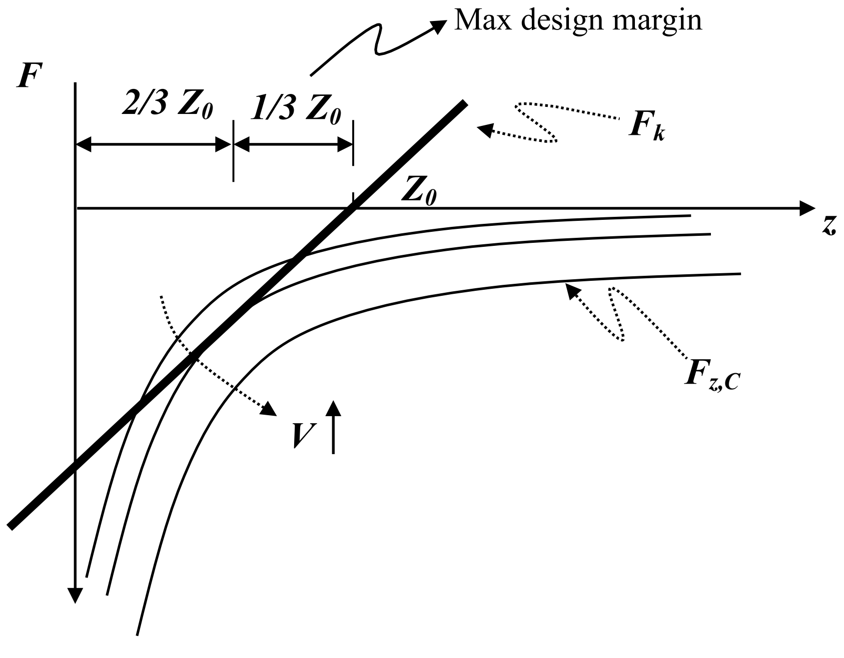


$$F_{z,C} = \frac{-1}{2} N_z \left(\frac{k\varepsilon_0 WX}{z^2}\right) V^2 \quad \textbf{(8-15)}$$

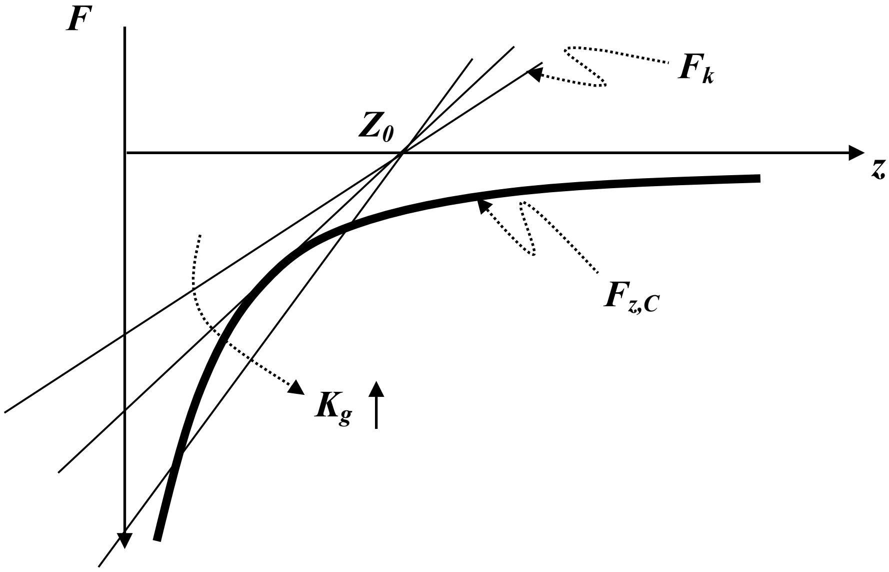
$$F_k = K_g(z - Z_0) = F_{z,C} = \frac{-1}{2} N_z \left(\frac{k\varepsilon_0 WX}{z^2}\right) V^2$$

(8-26)

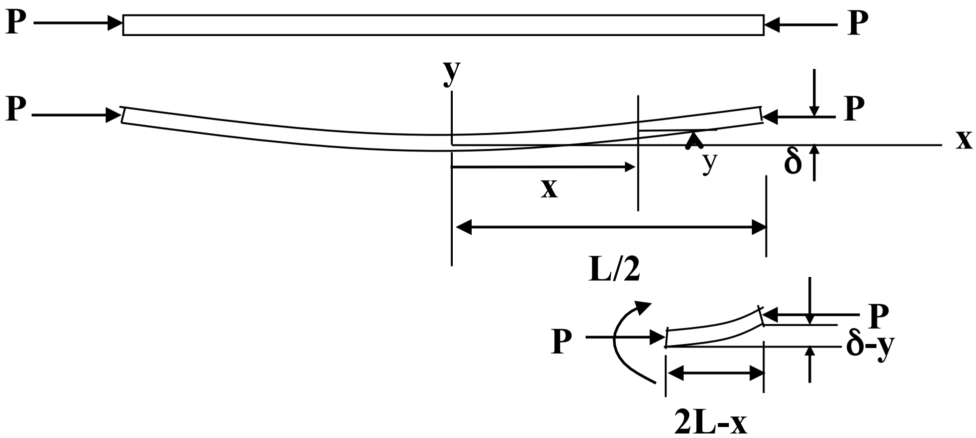
Different voltages:



Different spring constants:



2. Buckling of a long beam



$$EI\frac{d^2y}{dx^2} = M_r = P(\delta - y) \qquad \textbf{(8-27)}$$

with boundary condition:

$$\begin{cases} x = 0,\ y = \dfrac{dy}{dx} = 0 & (8-28-1) \\ x = \dfrac{L}{2},\ y = \delta & (8-28-2) \end{cases}$$

The solution for the first boundary condition

$$y = \delta(1 - \cos\sqrt{\frac{P}{EI}}x) \qquad \textbf{(8-29)}$$

To satisfy the second condition:

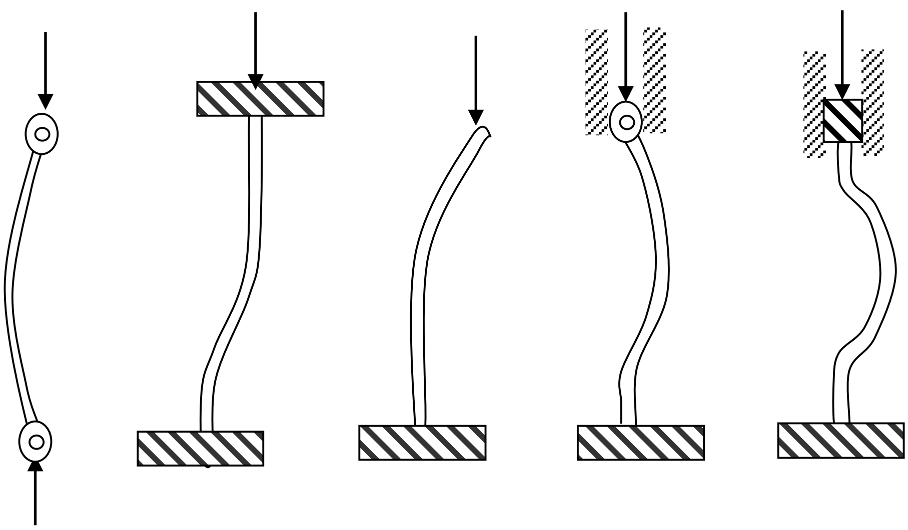
$$\cos\sqrt{\frac{P}{EI}}\frac{L}{2} = 0$$

$$\Rightarrow \quad \sqrt{\frac{P}{EI}}\frac{L}{2} = \frac{\pi}{2}, \frac{3\pi}{2}, \frac{5\pi}{2}, \ldots \qquad \textbf{(8-30)}$$

Take the minimum one:

$$=> \quad P_{critical} = \frac{\pi^2 EI}{L^2} \qquad \textbf{(8-31)}$$

For different buckling types:

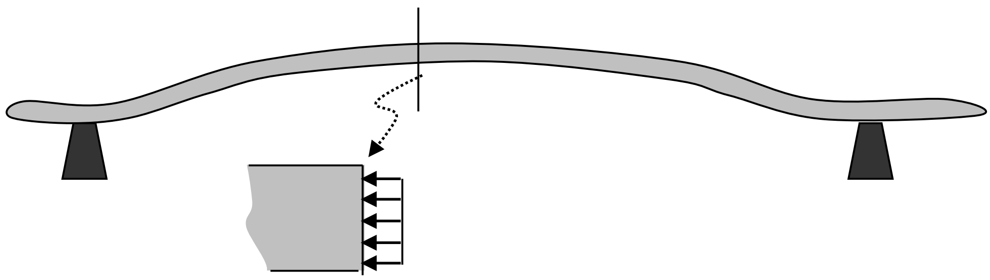


1 1 1/4 2 4 (· $P_{critical}$)

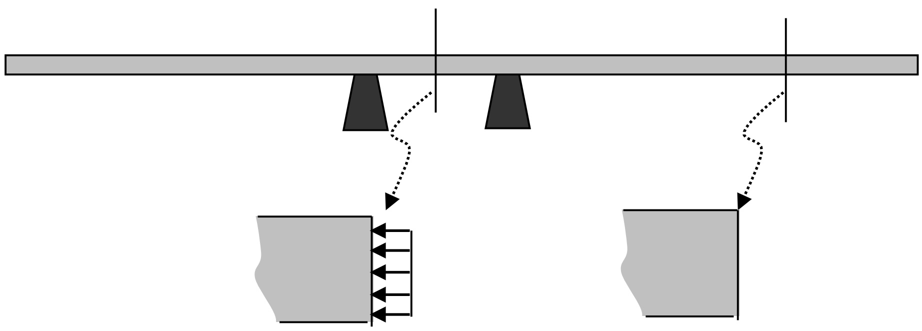
3. Stress of a long beam

a. Uniform Tensile and compressive stress

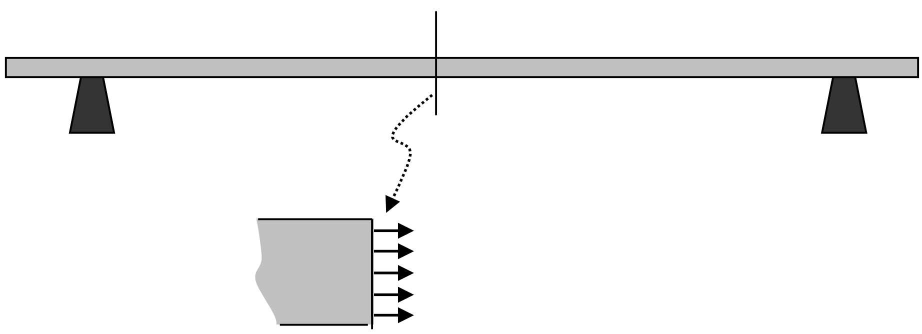
Compression:



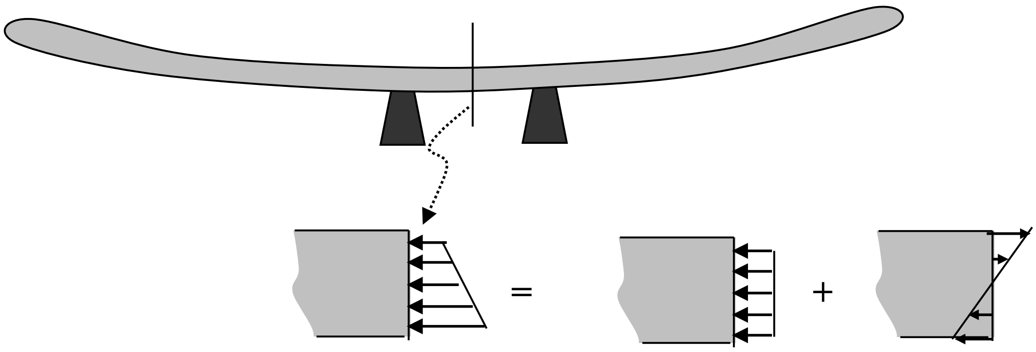
Better support design under compressive stress



Tension:



b. Non-uniform residual stress



4. Stiction during releasing

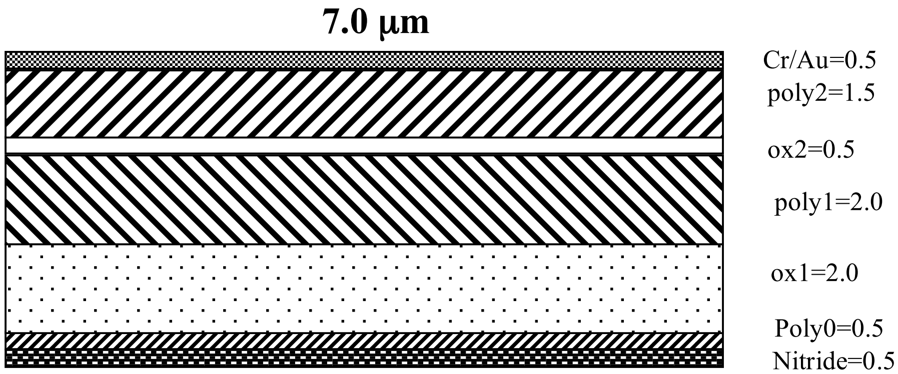
To overcome:

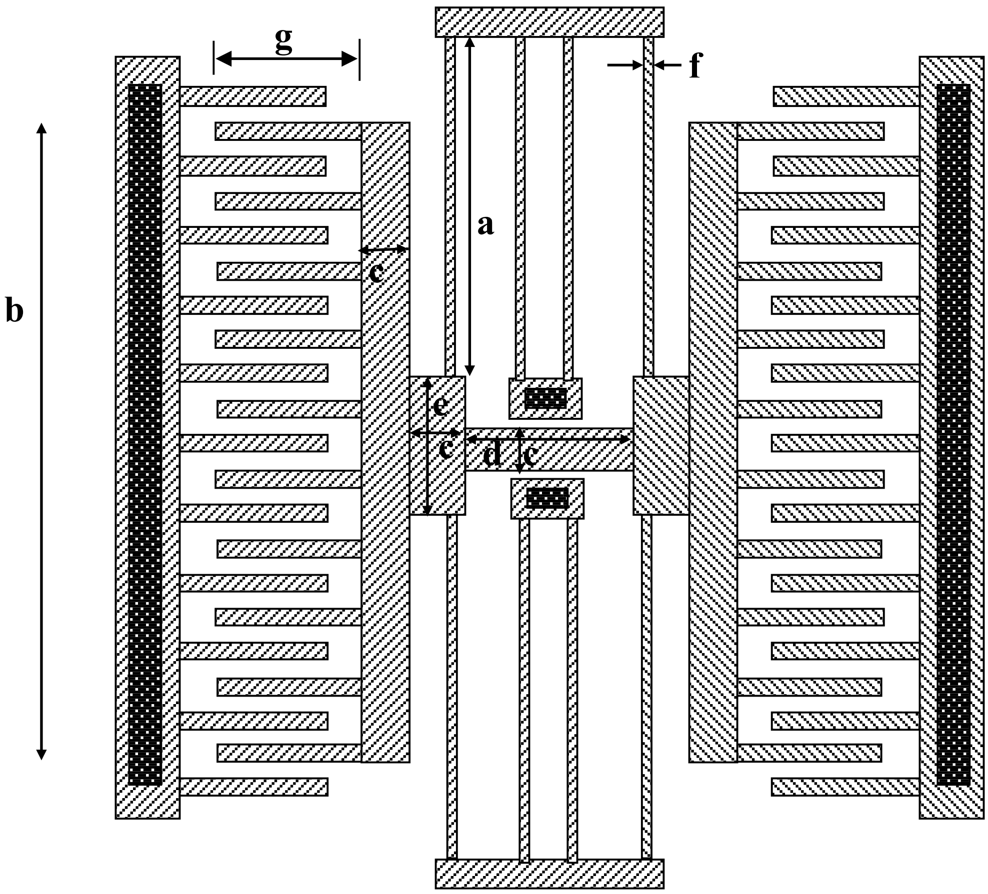
a. Reduce total length of the device.

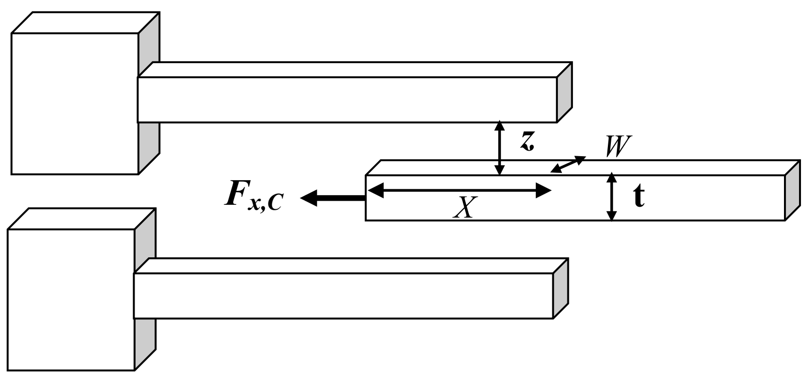
b. Employ residual stress to curl up device slightly

c. Special releasing technique

d. Example of # plug in:







Values for plug in:

$$
\begin{cases}
a = 120\ \mu m \\
b = 112\ \mu m \\
c = 12\ \mu m \\
d = 30\ \mu m \\
e = 24\ \mu m \\
f = 2.0\ \mu m \\
g = 30\ \mu m \\
X = 20\ \mu m \\
W = 3.5\ \mu m \\
z = 2.0\ \mu m \\
t = 4.0\ \mu m \\
E_{poly} = 140\ GPa \quad (Yang's\ \mathrm{mod}ulus) \\
\rho_{poly} = 2.3\ g/cm^3 \quad (Density) \\
N_z = 20
\end{cases}
$$

1. **Proof mass**

$$M = \rho W(2bc + 2ce + cd + 20tg) = 48.49\ ng$$

2. **Spring constant**

$$K = 8 \times \frac{EWf^3}{4a^3} = 4.56\ N/m$$

3. **Frequency response**

$$\omega_n = \sqrt{\frac{K}{M}} = 306498 \quad rad/s, \quad f_n = 48.78\ kHz$$

4. Damping

$$b = \frac{\omega_n M}{Q} = \frac{1.486e^{-5}}{100} = 1.486e^{-7} \quad Ns/m$$

assume Q=100

5. Maximum Force

$$F_{x,C} = \frac{1}{2} N\varepsilon_0 V^2 \frac{W}{z} = 1.55 \quad \mu N$$

assume V=100 volts

6. Maximum displacement

$$F_{x,C} = \frac{1}{2} N\varepsilon_0 V^2 \frac{W}{z} = F_k = K\Delta x$$

$$\Rightarrow \Delta x = \frac{1}{2} N\varepsilon_0 V^2 \frac{W}{Kz} = 0.34 \quad \mu m$$

7. Buckling strength of the beam

$$P_{buckle} = 2 \times 4 P_{critical} = 8\frac{\pi^2 EI}{a^2} = \frac{2\pi^2 EWf^3}{3a^2} = 1.79 \quad mN$$

8. Input power

$$W_{in} = \int IVdt = \int \frac{dQ}{dt} Vdt = \int_0^{\tau} V^2 dC = CV^2 \Big|_0^{\tau} = 1.05 \times 10^{-12} \quad Energy(J)/cycle$$

9. Output power

$$W_{out} = \int_0^{\Delta x} (F_{x,C} - F_k) dx = \int_0^{\Delta x} (\frac{1}{2} N\varepsilon_0 V^2 \frac{W}{z} - Kx) dx = \frac{1}{2}(N\varepsilon_0 V^2 \frac{W}{z} \Delta x - K\Delta x^2)$$

$$= 0.53 \times 10^{-12} \quad N \cdot m / cycle$$

9. Efficiency

$$\eta = \frac{W_{out}}{W_{in}} = \frac{0.53}{1.05} = 50.47\%$$