Lunar Transmissions Tower Material Selection

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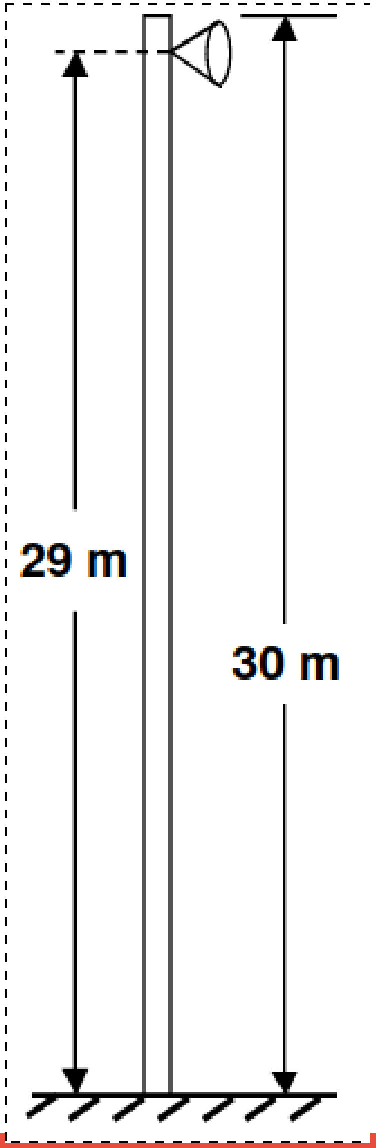
Slides for Design Problem #3

The Problem

-Transmission tower on moon subject to temperature range of -75 ℃ to +100 ℃.

-Need design that keeps dish within 10 mm (0.01 m) of its original position.

-Thermal strain coefficient of most materials too large to meet this requirement.



Advantages of Piezoelectric Materials

-Piezoelectric properties meet displacement requirement at extreme temperatures.

-Lower thermal strain

-Contracts under electric field

-Combine with base to improve a its material’s thermal performance.

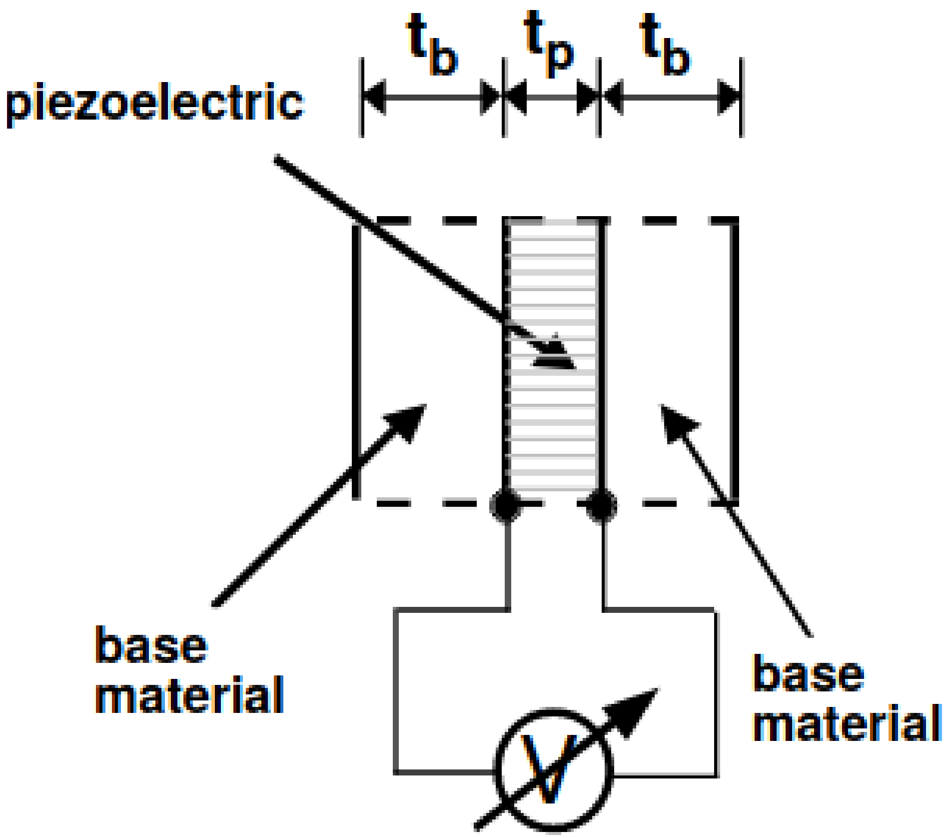
Approach/Concept

-Piezoelectric sandwiched between base material.

-Equal strain for both.

-Stresses balance based on thickness ratio.

-Apply voltage to reduce higher temp displacement.

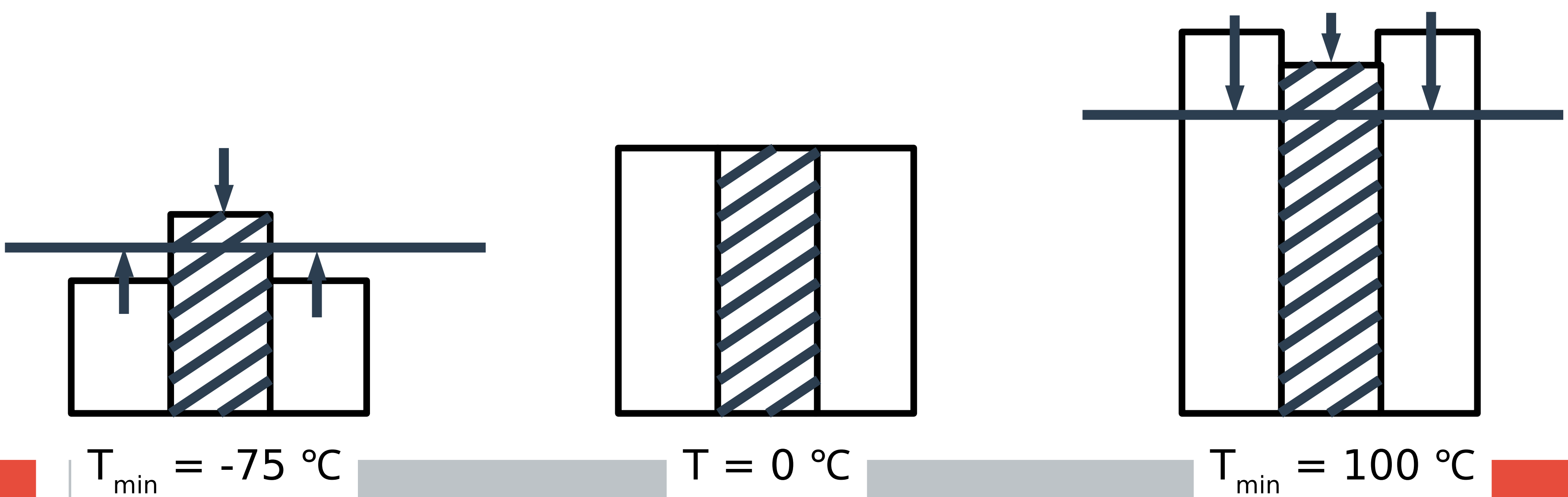


Approach/Concept

-Thicknesses sized for T_{min} with no electric field

- -Electric field only needed at T_{max}, in full sunlight.
- -Balance stress between materials and meet requirement.

-Then calculate stresses at T_{max} and electric field needed to meet displacement requirement



Design Tradeoffs

-Cheaper materials have higher thermal strain.

-Higher thermal strain has drawbacks:

-More piezoelectric to counteract greater displacement.

-More electricity to counteract greater displacement.

-Results in greater internal stress of material.

Governing Equations

-Base material strain

$$\varepsilon_b = \alpha_{bl}\Delta T + \sigma_{b1}/E_b$$

-Piezoelectric material strain

$$\varepsilon_p = E_k d_{113} + \alpha_p \Delta T + \sigma_{p1}/E_p$$

-Relationship of self-equilibrating stresses

$$2\sigma_{b1}t_b + \sigma_{p1}t_p = 0$$

Results

Mat'l Combo	t_b/t_p	E_k (V/m)	Max base stress (MPa)	Max piezo stress (MPa)
Al – PZT 4	0.00240	9.394e-07	138	0.66
Al – PZT 5H	0.00180	4.217e-07	138	0.50
Al – PZT 5A	0.00199	6.757e-07	138	0.55
Ti – PZT 4	0.00664	9.552e-07	59.4	0.79
Ti – PZT 5H	0.00498	4.288e-07	59.4	0.59
Ti – PZT 5A	0.00550	6.871e-07	59.4	0.65
AS4 – PZT 4	0.01319	9.653e-07	32.9	0.87
AS4 – PZT 5H	0.00989	4.333e-07	32.9	0.65
AS4 – PZT 5A	0.01093	6.943e-07	32.9	0.72
P70 – PZT 4	0.79912	2.0e-06	5.64	9.01
P70 – PZT 5H	0.48528	8.0e-07	5.64	5.47
P70 – PZT 5A	0.63076	1.4e-06	5.64	7.11

Other Considerations

-Internal stresses

-Strains induce stress with potential to cause failure.

-Structural stability

-Design will need to meet stability requirements; usually met by increasing cross-section area (i.e., more material).

-Fatigue and cracking

-Cyclic loading of contraction and expansion can create or propagate cracks. Less stress increases the life of the design.

Recommendations

-High Modulus Graphite/Epoxy Layup B (P70/3501-6) base with PZT 4 piezoelectric.

-This layup is flexible to meet displacement and other design requirements.

- -Lower thermal strain than piezo. This is only combination where electric field and thickness ratio can be traded off.
- -Other materials constrained by T_{min} displacement for sizing.
- -Can design for electricity, stability, and/or lifing requirements.