Fully Coupled Constituitive Model for Electrostrictive Ceramic Materials -Hom and Shankar

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Adaptive Structure

❖ Active smart materials system

Sensors … to detect changes in environment
actuators … used in a feedback loop to respond to those changes

❖ Most common ceramic materials

- Piezoelectrics … based on lead zircomate titanate $Pb(\mathrm{Zr}, Ti)\ \mathrm{O}_3$
  - can convert electrical energy into small but accurate displacements with a fast response time
  - more compact, consume less power, less prone to overheating
  - can detect minute displacements by converting mechanical work into electrical energy

Adaptive Structure

- electrostrictive ceramics
  - ◦ generally offer higher electrically induced strains with lower hysteresis
  - ◦ but with the penalties of complicated electromechanical behavior and temperature dependency
  - ◦ electromechanical coupling efficiency for eletrostrictors is comparable to that for piezoelectrics

◦ { piezoeletrics, electrostrictor } → belong to a class of ionic crystals known as ferroelectrics

- Ferroelectrics … consist of subvolumes, called domains that have a uniform, permanent, reorientable ,polarization
- direction of polarization for each domain is randomly oriented → the crystal itself has no not bulk polarization

Adaptive Structure

- Above a characteristic temperature (the Curie temperature), a ferroelectric undergoes a transition where the spontaneous polarization disappears
- Piezoelectricity is induced in a ferroelectric ceramic by applying a high electric field at elevated temperatures during manufacture → "poling" process
  → partially aligns the polar axes of the domains to create a macroscopic polarization in the crystal.
- The resulting piled-piezoelectric will deform when subjected to an electric field and polarize when mechanically stressed

for low electric field $[< 0.1MV/\mathrm{m}\ \text{for}\ Pb(\mathrm{Zr},\mathrm{Ti})O_3]$

electrically induced strain $\propto$ the applied field

electric field $\propto$ induced polarization

For higher AC fields $[> 0.6 \sim 1.1MV/\mathrm{m}\ \ peak - peak]$

significant electromechanical hysteresis

→ can create servo-displacement control problems

Adaptive Structure

❖ Electrostrictiction

- induced strain $\propto$ (induced polarization)^2
- the same deformation occurs when the field is reversed, in contrast to piezoelectricity
- relaxor – ferroelectrics can exhibit large electrostricve strains
- spontaneous polarization is not suddenly lost at a specific Curie temperature but slowly decays with increasing temperature
- significant electrostriction with minimal hysteresis is possible both above and below the nominal transition temperature
- most promising relaxor – ferroelectrics materials … lead magnesium niobate

  $Pb(Mg_{1/3}\ Nb_{2/3})\ O_3(PMN)$, or its solid relations with lead titanate

  $Pb(Mg_{1/3}\ Nb_{2/3})\ O_3 - PbTiO_3\ (PMN - PT)$
- high electrically-induced strains (~0.1%) and low hysteresis (<5%) over moderate electric fields $(\sim 1\ MV/m\ \ peak - peak)$