Modeling structures with piezoelectric materials in SDT

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The Structural Dynamics Toolbox (SDT) for MATLAB

- **FEM simulations**
- System models (model reduction, state-space, active control)
- Experimental modal analysis
- Test/analysis correlation, model updating

- General toolbox (programmatic access to all levels from pre-post to element level iterations)
- Custom applications (pantograph/catenary, visco, rotor, squeal, ...)
- Customer base ensures maintenance: more than **750** licenses installed in **15** countries with users at Bosch, Boeing, Daimler/Chrysler, EADS, EDF, Ford, LANL, NASA, ONERA, PSA, Renault, Rockwell, Siemens, Sony, Valeo, etc.
The Structural Dynamics Toolbox (SDT) for Matlab

General 3-D Finite Element Modelling with an open architecture allowing easy user development of new multi-physics elements, ...

NEW The piezoelectric module

3D elements

Multi-layer plate elements
Main functionalities

- **3D elements** for detailed modelling of piezoelectric systems such as actuators and sensors

- **Multi-layer plate elements** allowing to model plate structures equipped with thin piezoelectric transducers including piezocomposites such as Macro Fiber Composites (MFCs)

- Simple handling of **electrical boundary conditions** through the definition of electrodes. Combinations of voltage as well as charge can be applied and/or measured on the electrodes

- Advanced **visualisation tools** (electric field, electrode areas, charge density on electrodes)

- Static **periodic homogenization** of representative volume elements (RVE) for the modelling of piezocomposite transducers

- Possibility to export the model in the state-space format to be used for active control or passive shunt applications.
Main steps of an analysis

SDT supports piezoelectric constitutive laws for all 3D volume elements and composite shells. The main steps of an analysis are:

- define/import mesh.
- define piezoelectric material properties
- define electrodes through an MPC for volumes or the element property for shells.
- define electric boundary conditions, loading, and sensors
- compute the response using full order or reduced order models
- visualize the response in more detail.
Piezo volumes and transfers: accelerometer example

Computation of the sensitivity of the accelerometer to a base excitation. Comparison of voltage vs charge sensitivity
Piezo volumes and advanced views: IDE example

a) $d_{31}$ mode  
b) $d_{33}$ mode - interdigitated

Visualisation of the curved electric field when using interdigitated electrodes
Piezo volumes: periodic homogenization of piezocomposite transducers

**d31 P2-type MFC**

- Polymide film with continuous
- Epoxy layer
- PZT Macro Fibers
- Matrix epoxy

**RVE**

**Electrodes**

**d33 P1-type MFC**

- Polymide film with interdigitated electrodes
- Epoxy layer
- PZT Macro Fibers
- Matrix epoxy

**RVE**

**Electrodes**
Piezo volumes: periodic homogenization of piezocomposite transducers

**Electrical boundary conditions**

All faces with the normal in the plane of the actuator blocked

**Mechanical boundary conditions**

$\Delta V = 0$
Piezo volumes: periodic homogenization of piezocomposite transducers

Computation of the six local problems using SDT: P2 MFC

Post-processing to get the homogeneous properties as a function of the volume fraction of fibers $\rho$
Piezo volumes: periodic homogenization of piezocomposite transducers

Computation of the six local problems using SDT: P1-MFC

Post-processing to get the homogeneous properties as a function of the volume fraction of fibers $\rho$
Piezo shells and transfers: plate with 4 piezoelectric patches

Piezoelectric patches (two on each side)

Static response to a voltage applied to the blue patch
Transfer function between a voltage applied to one patch and the charge measured on another patch – comparison between full and reduced order (state-space) models.
Piezo shells and transfers: plate with 4 piezoelectric patches

Combination of patches to induce pure bending of the plate. The FRF represents the tip displacement of the beam.
Integrating thin piezocomposite transducers in plate models

Multi-layer model

Electrode layers (copper + epoxy)

Active layer properties obtained from 3D piezo homogenization

Static response to voltage applied on the MFC
Using shaped orthotropic piezoelectric transducers: triangular point load actuator

Static response
Using shaped orthotropic piezoelectric transducers: triangular point load actuator

Comparison between the collocated transfer function for the triangular actuator and for a real point load at the tip of the triangle
Vibration damping using a tuned resonant shunt circuit

Effect of an RL shunt tuned on the first mode shape
The piezoelectric module of SDT

- Is a Matlab-based tool that offers both 3D and shell elements for the modelling of structures with piezoelectric materials
- Allows to import meshes from most commercial codes (Ansys, Nastran, Abaqus, Samcef) and treat complex problems with a large number of degrees of freedom
- Provides efficient tools for the definition of piezo material properties (existing database) and electrodes including combinations
- Enables to compute static and dynamic responses to voltage/charge actuation and define voltage/charge sensors using full and reduced order models
- Contains advanced visualization tools for easy pre and post-processing
- Allows to create reduced order State-space models from the full models for use with the control toolbox in Matlab

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