Piezo-Electric and Shape Memory Elements for SIMPACK

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**Speaker**

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Overview

• Technical applications
• Piezo-electric element
• Shape memory element
• Example of use
• Abstract and further steps
Piezo-Electric and Shape Memory Elements for SIMPACK

Technical applications

- Transportation
- Robotic
- Mechanical engineering
- Medicine

Combination: motion, deformation, smart technology
Piezo-Electric and Shape Memory Elements for SIMPACK

Piezo-Electric Element

Electro mechanic coupled equations

\[
\begin{bmatrix}
S_1 \\
S_2 \\
S_3 \\
S_4 \\
S_5 \\
S_6 \\
D_1 \\
D_2 \\
D_3
\end{bmatrix} =
\begin{bmatrix}
\begin{bmatrix}
E_{11} & E_{12} & E_{13} & E_{14} & E_{15} & E_{16} \\
E_{21} & E_{22} & E_{23} & E_{24} & E_{25} & E_{26} \\
E_{31} & E_{32} & E_{33} & E_{34} & E_{35} & E_{36} \\
E_{41} & E_{42} & E_{43} & E_{44} & E_{45} & E_{46} \\
E_{51} & E_{52} & E_{53} & E_{54} & E_{55} & E_{56} \\
E_{61} & E_{62} & E_{63} & E_{64} & E_{65} & E_{66} \\
D_{11} & D_{12} & D_{13} & D_{14} & D_{15} & D_{16} \\
D_{21} & D_{22} & D_{23} & D_{24} & D_{25} & D_{26} \\
D_{31} & D_{32} & D_{33} & D_{34} & D_{35} & D_{36}
\end{bmatrix}
\end{bmatrix} \begin{bmatrix}
d_{11} \\
d_{21} \\
d_{22} \\
d_{23} \\
d_{24} \\
d_{25} \\
d_{26} \\
d_{31} \\
d_{32} \\
d_{33} \\
d_{34} \\
d_{35} \\
d_{36}
\end{bmatrix} =
\begin{bmatrix}
T_1 \\
T_2 \\
T_3 \\
T_4 \\
T_5 \\
T_6 \\
E_1 \\
E_2 \\
E_3
\end{bmatrix}
\]

Inverse piezo-electric effect (actuator, 1D, 3 direction)

\[
S_3 = \frac{\Delta l_3}{l_3} = s_{33} \cdot T_3 + d_{33} \cdot E_3 \quad \Rightarrow \quad \Delta l_3 = s_{33} \frac{F_3}{A_3} l_3 + d_{33} E_3 l_3
\]

\[
F_3(t) = (\Delta l_{03} - \Delta l_3) \cdot c_{T3} \quad \Rightarrow \quad c_{T3}^E = \frac{A_3}{s_{33} l_{03}}
\]

\[
\Delta l_{03} = d_{33} E_3 l_3
\]

Piezo-electric effect (sensor, 1D, 3 direction)

\[
D_3 = d_{33} T_3 + \varepsilon_{33} E_3 \quad \Rightarrow \quad D_3 = 0 = d_{33} \frac{F_3}{A_3} + \varepsilon_{33} \frac{U_3}{l_0}
\]

\[
U_3 = \frac{d_{33} \cdot F_3}{C_3} \quad \Rightarrow \quad C_3 = \varepsilon_{33} \frac{A_3}{l_0}
\]
**Piezo-Electric Element**

- **Hysteresis**
  
  Dynamic operation
  
  \[ \dot{z}(t) = A \cdot n \cdot d_{33} \cdot \dot{U}(t) - B \cdot \left| \dot{U}(t) \right| \cdot z(t) - C \cdot \ddot{U}(t) \cdot \left| z(t) \right| \]

- **Creep**
  
  Quasi-static operation
  
  \[ d(t) = \Delta I_0(U(t)) \cdot D \cdot \log \left( \frac{t}{t_{Sprung}} \right) \]

\[ F(t) = (\Delta I_0 - \Delta I(t) - z(U(t)) + d(U(t))) \cdot c_F \]
Piezo-Electric and Shape Memory Elements for SIMPACK

**Piezo-Electric Element**

- Choice (dimension, material set, operation)
- Voltage (V(t) or control)
- Geometry (n, l, A)
- Material (d_{ij}, s_{ij}, \varepsilon_{ij}, hysteresis, creep)

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![Diagram of Piezo-Electric Element](image)
Piezo-Electric and Shape Memory Elements for SIMPACK

Piezo-Electric Element

Beam with piezo-actuator
U = 100V, x at free end

Experiment: 1,3mm
SIMPACK: 1,1mm

• Stiffness of the basic structure
• Stiffness of the coupling
• Location of the coupling
Piezo-Electric and Shape Memory Elements for SIMPACK

**Shape Memory Element**

- **One-way-effect**
  - Heat up
  - Cool down
  - Deform

- **Two-way-effect**
  - Cool down
  - Heat up

- **Super elastic**
  - Heat up
  - Cool down
  - $F(t)$

- **Graphical representations**
  - Deformation vs. temperature ($\epsilon$ vs. $\vartheta$)
  - Stress vs. strain ($\sigma$ vs. $\epsilon$)
  - Transition points $M_F$, $M_S$, $A_S$, $A_F$
Piezo-Electric and Shape Memory Elements for SIMPACK

**Shape Memory Element**

- **Phase transformation**
  - Twinned Martensite
  - Deformed Martensite
  - Austenite
  - Plastic Deformation

- **Effects**
  - One-way-effect (A)
  - apparent Two-way-effect (B)
  - Two-way-effect (C)
  - Superelastic (D)
Piezo-Electric and Shape Memory Elements for SIMPACK

Shape Memory Element

- Phase
  \[ \xi = \xi_S + \xi_T \]
  Phase transformation by Cosinus-Model
  additional jump condition

- Thermo-mechanic phase transformation by Brinson-Model
  \[ \sigma - \sigma_0 = E(\xi)\varepsilon - E(\xi_0)\varepsilon_0 + \Omega(\xi)\xi_S - \Omega(\xi_0)\xi_{S0} + \Theta(T - T_0) \]  
  \[ \Omega(\xi) = -\varepsilon_L E(\xi) \quad \Theta(\xi) = \alpha(\xi) E(\xi) \]  
  FEM \to MKS: \[ \sigma = \frac{F}{A} = E \varepsilon = E \frac{\Delta l}{l} \]
  \[ F = (E(\xi)\varepsilon + \Omega(\xi)\xi_S + \Theta(T - T_0))A \]
  No Prestress: \[ \sigma_0 = \varepsilon_0 = \xi_{S0} = 0 \]

- Extension of the Brinson-Model (1D – one-way / two-way / multi-way)
  \[ F - F_0 = (E(\xi)\varepsilon + \Omega(\xi)\xi_S + \Omega_2(\xi)(1 - \xi) + \Theta(T - T_0) - E(\xi)\varepsilon_0)A = F_{ges} \]
  \[ \Omega_2(\xi) = -\varepsilon_2 E(\xi) \]
  One-way-effect \( \varepsilon_2 = 0 \) / Two-way-effect \( \varepsilon_L = \xi_S = 0 \)
Piezo-Electric and Shape Memory Elements for SIMPACK

Shape Memory Element

- Choice (tension / pressure, one-way-/two-way-/multi-way-effect)
- Temperature (T or control)
- Geometry (l, A)
- Material ($E_A$, $E_M$, $\alpha_A$, $\alpha_M$, $\varepsilon_L$, $\varepsilon_2$, $\xi_S$, $\xi_T$, $\sigma_s^{cr}$, $\sigma_f^{cr}$, $M_S$, $M_F$, $A_S$, $A_F$, $C_M$, $C_A$)

F(t)

Control

SIMPACK MBS Force Element

File

Name: [Material element name]

From Marker: [Marker 1]

To Marker: [Marker 2]

Database: [Database]

Identify No.: [Identify number]

Force Type: [Force type]

Parameters

- Gedächtnis-Effekt
- Richtungsfaktor ($\xi$)
- Kraftschwerpunkt ($P_0$)
- Anteil temp, anschließt $x_0$
- Anteil span, anschließt $x_0$
- Eingabeart der Temperatur
- Temperatur-Zeit-Funktion

- $F(t)$

- $\sigma_s^{cr}$
- $\sigma_f^{cr}$
- $M_S$
- $M_F$
- $A_S$
- $A_F$
- $C_M$
- $C_A$
Example of use

Circular table as a part of a high-precision machine system

source: Wiemers innovative Technik GmbH Magdeburg/Barleben company
Example of use

Problem: tare, payload
- Local static deformation of clamping plate, flange of the rotor and housing cover

Problem: tool contact, magnetic bearing
- Local dynamic deformation of clamping plate, flange of the rotor and housing cover

Problem: unbalanced rotation
- Revolving local static deformation of the clamping plate and the flange of the rotor
- Revolving local dynamic deformation of the housing cover
Abstract and further steps

• Aim: piezo-electric and a shape memory force element in SIMPACK to model adaptive Structure
• Special options in piezo-electric element: hysteresis, creep
• Further steps: magneto-strictive, electro-rheological, magneto-rheological or electro-chemical elements …