Magnetostriective Actuation of a Smart Beam with Hysteretic Material Behaviour

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Introduction

Aim of this work:
Predicting the behaviour of a magnetostrictively actuated beam, considering a nonlinear field-strain relation

Constitutive Equations

\[
\{\varepsilon\} = [S] \{\sigma\} + [d]^T \{H\} \\
\{B\} = [d] \{\sigma\} + [\mu] \{H\}
\]

- \([S]\): elastic compliance
- \([d]\): magneto-mechanical coupling coefficient
- \([\mu]\): permeability
Tip displacement prediction and measurement of an actuated magnetostrictive cantilever beam
- Magnetic field is parallel to the solenoid axis

- Magnetic field at the centre:

$$H = I \frac{N}{2(R_1 - R_2)} \ln \left( \frac{\sqrt{R_2^2 + (L/2)^2} + R_2}{\sqrt{R_1^2 + (L/2)^2} + R_1} \right)$$

- Actuator material:
  TX-GMM (equal to Terfenol-D)
  $$d_{11} = 1.1 \cdot 10^{-8} \text{m/A}$$
Theoretical Approach

\[ W_e = W_i \]

\[ \int_{V_2} \sigma_i \cdot \varepsilon \, dV_2 = \int_{V} \sigma \cdot \varepsilon \, dV \]

\[ \sigma_i = d_{11} \cdot H_1 \cdot E_2 \]

\[ \Rightarrow -M_i = w'' \cdot EI \]

\[ M_i = d_{11} \cdot H_1 \cdot E_2 \cdot b_2 \cdot t_2 \cdot \left( t_1 + \frac{t_2}{2} - z_s \right) \]
Nonlinear Field-Strain Relation

- Crawley & Lazarus (1989) for piezoceramic actuators

\[ \varepsilon_{11} = d_{31}^{(0)} E_3 + d_{31}^{(1)} E_3^2 \]

\[ d_{31}^* = \frac{\varepsilon_{11}}{E_3} \]

\[ d_{31}^* = d_{31}^{(0)} + d_{31}^{(1)} E_3 \]

\[ d_{31}^* = \frac{d_{31}^{(0)}}{2} + \sqrt{\left( \frac{d_{31}^{(0)}}{2} \right)^2 + d_{31}^{(1)} \varepsilon_{11}} \]
Actuator Characterisation with the Michelson Interferometry

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Experimental Results

Hysteresis of a free magnetostrictive actuator

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Preisach Model

\[ f(t) = \int_{\alpha \geq \beta} \mu(\alpha, \beta) \hat{\gamma}_{\alpha\beta} u(t) \, d\alpha \, d\beta, \]

\( \mu(\alpha, \beta) \): Preisach function
\( \hat{\gamma}_{\alpha\beta} \): hysteresis operator
Numerical Evaluation of the Preisach Output

increasing input:

\[ f(t) = f_{\alpha_0\beta_0} + \sum_{k=1}^{n-1} \left( f_{M_k}m_k - f_{M_k}m_{k-1} \right) + f_u(t)u(t) - f_u(t)m_{n-1} \]

decreasing input (\(\alpha = \text{const.}\)):

\[ f(t) = f_{\alpha_0\beta_0} + \sum_{k=1}^{n-1} \left( f_{M_k}m_k - f_{M_k}m_{k-1} \right) + f_{M_n}u(t) - f_{M_n}m_{n-1} \]

\(M_k, m_k\): max. and min. input values stored in the history
- parameter surface determined from the descending curves using linear and cubic spline interpolation
Verification of the Numerical Model

Result of the Preisach model in comparison with the experimental results

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Validation of the Numerical Example

- best results are obtained using the magneto-mechanical coupling coefficient as a function of the magnetic field
- the nonlinear coupling coefficient is determined with the Preisach model
Prediction of Arbitrary Path

- based on the Preisach model, the behaviour of the active beam can be predicted for an arbitrary loading path.
Summary

- Experimental determination of a magnetostrictive actuator hysteresis
- Parameter identification for the Preisach model
- Simulation of the behaviour of a free actuator
- Simulation of a smart beam
- Validation of the theoretical results
Thanks for your attention!