SMA ACTUATORS FOR SHAPE CONTROL OF STRUCTURES AND MATERIALS

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ADAPTIVE MATERIALS

- electro-rheological fluids
- magneto-rheological fluids
- piezo-electric ceramics
- pieze-electric polymers
- shape memory alloys

field

- electric
- magnetic
- temperature

changed properties

SMA : NiTi
SHAPE MEMORY ALLOY (SMA); Nitinol

1. temperature change ; unrestrained : $\Delta \varepsilon \leq 8\%$

2. axial (dead) load

- two-way material : elongation at temperature drop
- one-way material : elongation at temp. drop + axial load
PHASE TRANSFORMATION

martensite ↔ austenite

martensitic fraction : $0 \leq m \leq 1$
STRESS-STRAIN CURVE

\[ \varepsilon = \frac{1}{2} \left\{ \left( \frac{l}{l_0} \right)^2 - 1 \right\} \]

\[ p = \frac{Fl_0}{lA_0} \]

\[ \theta > \theta_{\text{af}} \]
STRESS-STRAIN CURVES

\[ \theta < \theta_{mf} \]
\[ \theta_{mf} < \theta < \theta_{ms} \]

\[ \theta_{ms} < \theta < \theta_{af} \]
\[ \theta > \theta_{af} \]

\[ \theta \gg \theta_{af} \]
STRESS-STRAIN CURVES FOR $\theta > \theta_{af}$

\[ p \]

$\theta > \theta_{af}$

$\rho_{mf}$

$\rho_{ms}$

$\rho_{as}$

$\rho_{af}$
LINEAR STRESS-STRAIN DEPENDENCY

\[ p = p_{af} + \xi (p_{ms} - p_{af}) + m (p_{as} - p_{af}) + \xi m (p_{mf} + p_{af} - p_{ms} - p_{as}) \]

\[ = p_1 + \xi p_2 + m p_3 + \xi m p_4 \]

\[ \varepsilon = \varepsilon_1 + \xi \varepsilon_2 + m \varepsilon_3 + \xi m \varepsilon_4 \]
LINEAR TEMPERATURE DEPENDENCY

- transition points ~ temperature : linear

\[
\begin{align*}
  p_i &= p_{ia} \theta + p_{ib} \\
  \varepsilon_i &= \varepsilon_{ia} \theta + \varepsilon_{ib}
\end{align*}
\]

\[\rightarrow \quad 16 \text{ material parameters}\]
<table>
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<th>[K$^{-1}$]</th>
<th>$5.7 \cdot 10^{-5}$</th>
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APPLICATIONS

• impact resistant material
• on/off applications (also: clamping devices)
• continuous mode applications

actuators in robots
  (prostheses, adaptive truss structures)
active fibres in composites

→

trajectory control
vibration control
shape control

− advantages:
  * quiet
  * efficient
  * small and lightweight
  * activation with electric current: fast

− disadvantages
  * only tensile loads for wires
  * cooling by heat exchange with surrounding medium: slow

− control procedure necessary
TRAJECTORY CONTROL IN TRUSS STRUCTURES

• prescribed trajectory of structure point(s) or constant position of point(s) under variable loads
• feed back control: no model needed minimize deviation of desired trajectory
• open loop control: model needed for simulation EEM + (p, ε, θ)-relation for SMA wire
• calculate control action (Δθ → θ → I)
CONTROL STRATEGIES : TEST SETUP

l_0 = 178.5 [mm] ; A_0 = 0.05 [mm^2] ; M = 1.63 [kg] ; \theta_\infty = 22 [\degree C]

desired trajectory : q_d(t)

\downarrow \text{discretisation} \rightarrow q_{d,i+1}

sample frequency : f_s = 20 [Hz] \rightarrow t_{i+1} - t_i = 1/20 [s]
feedback

potentiometers $\rightarrow \phi$ $\rightarrow \Delta\phi = \phi_d - \phi$ $\rightarrow I_{FB}$

open loop

mechanical model
heat balance
material model SMA
\{ $\rightarrow I_{OL}$
TRACKING RESULTS
SMA BEAM & "PLATE"

SMA wires

PP matrix

actuated
SMA
wires

neutral
axis

inactive
SMA
wires

1.6

115

7
TRACKING RESULTS

- saddle shaped sinusoidal trajectory ; FB + OL control

![Graphs showing tracking results with sinusoidal and sawtooth trajectories with FB and FB+OL control.]

![Bar chart showing comparison of control methods with legend: saddle, spherical, cylindrical.]

(fb) (sinusoidal) (spherical) (sawtooth) (cylindrical) (sawtooth)
CONCLUSIONS

• SMA (NiTi)
  – high force per unit weight / volume
  – good long term behaviour
  – light and small actuators
  – no reduction gear necessary
  – no noise
  – easy fast heating / slow cooling

• control algorithm
  – OL diminishes tracking error
  – avoid boundaries of working range SMA
  – more links → redundancy → optimization

• measurement systems
  – easier measurements needed
    * potentiometers → Hall-effect sensors
    * camera system → fiber optics