Abstract

Shape memory alloys are a unique class of thermally activated materials capable of large recoverable strains. SMA springs extend the linear actuation capabilities of SMA wire by offering greater stroke actuation. SMA actuators also have the potential for being self-sensing elements. This can be achieved by leveraging the material’s dependency of electrical resistance on material strain. This research explores the new domain of SMA controllability with a focus on the self-sensing capabilities of low spring index SMA springs through power controlled thermo-mechanical characterizations.

SMA Springs

SMA Background

SMA is a NiTi alloy defined by its diffusionless solid state phase transformations. This mechanism allows the material to recover shapes when heated above an activation temperature. Shape can be retrained by annealing at temperatures much higher than the austenite transition temperature. This process is called shape setting.

SMA Spring Manufacturing

A novel CNC spring winding machine was fabricated to manufacture consistent SMA coil prototypes. SMA spring behavior is dependent on packing density, spring index, the number of active coils, annealing time and temperature, and quenching method.

Self-Sensing Experimental Design

An experimental setup was designed and manufactured to characterize the thermo-mechanical actuation behavior of SMA coil prototypes.

Five SMA spring prototypes were manufactured. Varying spring index creates a range of anticipated coil behavior.

<table>
<thead>
<tr>
<th>Wire Diameter</th>
<th>Pitch Angle</th>
<th># of Coils</th>
<th>Spring Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mil</td>
<td>0</td>
<td>80</td>
<td>5.8</td>
</tr>
<tr>
<td>6 mil</td>
<td>0</td>
<td>80</td>
<td>5</td>
</tr>
<tr>
<td>8 mil</td>
<td>0</td>
<td>80</td>
<td>4</td>
</tr>
<tr>
<td>10 mil</td>
<td>0</td>
<td>80</td>
<td>3.4</td>
</tr>
<tr>
<td>12 mil</td>
<td>0</td>
<td>80</td>
<td>3</td>
</tr>
</tbody>
</table>

Experimental Procedure

- Final Twinned Martensite Prototype
- Final De-Twinned Martensite Prototype

Results

12 mil Prototype Characterization

The load-deflection hysteresis of the coil closely resembles the stress strain characteristic of a conventional linear SMA actuator.

- Max load: 5.17N
- Max deflection: 95.8 mm
- $K_S = 0.1739 \text{ N/mm}$
- $K_{DS} = 0.0931 \text{ N/mm}$

The spring experienced rapid changes in deflection with resistance variation.

- Constant load: 1.47 N
- Max deflection: 56.2 mm
- Max strain: 342%

Conclusion

- Controlled power thermo-mechanical characterization of SMA springs closely emulates the stress-strain response of conventional linear SMA actuators.
- SMA coils produce very large recoverable strains (>300%).
- Cycle hysteresis is marked by a wide operating deflection within a narrow range of operating resistances.

Future Work

- 6 mil and 12 mil spring prototypes were tested. Additional prototypes must be thermo-mechanically characterized. The extent of experimental hysteresis will determine the control approach.
- It is hypothesized that the hysteresis band width is independent of wire diameter and applied force but dependent on cycling frequency.
- A physical model must be developed to accurately map variations in resistance to structural strain.