Mechanical Behaviour of Tape Springs Used in the Deployment of Reflectors Around a Solar Panel

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### OUTLINE

- **INTRODUCTION**
- **DEFINITION OF THE PROBLEM**
- **PARAMETRIC STUDIES**
- **OPTIMISATION**
- **CONCLUSIONS**
**Introduction - Reflectors**

**Main objective:** reduction of the mass for small satellites.

However, slower power consumption decrease for the electronic equipment.

**Solution:** deployment of solar panels with reflectors.

**In this work:** use of tape springs to deploy reflectors.
**INTRODUCTION - TAPE SPRINGS**

**Definition:** Thin strip curved along its width used as a compliant mechanism.

- Storage of elastic energy
- Passive and self-actuated deployment
- No lubricant
- Self-locking in deployed configuration
- Possibilities of failure limited

⇒ Valuable components for **space applications**.
**INTRODUCTION - TAPE SPRINGS**

**Mechanical behaviour:**

- Highly nonlinear
- Different senses of bending
- Buckling
- Hysteresis phenomenon

![Diagram showing bending moments and angles](image_url)
DEFINITION OF THE PROBLEM

Folded configuration: reflector folded on the top of the solar panel considered as clamped.

Deployed configuration: 120°.

Fixed parameters:
- Reflector: 200 × 200 mm², \( m = 0.4 \text{ kg} \)
- Two tape springs: \( L = 50 \text{ mm} \)
- Opposite sense

Design variables: \( t, R, \alpha \) with \( w \leq 30 \text{ mm}, h \leq 15 \text{ mm} \)
**DEFINITION OF THE PROBLEM**

**Material:** beryllium copper

<table>
<thead>
<tr>
<th>$E$</th>
<th>$\nu$</th>
<th>$\rho$</th>
<th>$\sigma_y$</th>
</tr>
</thead>
<tbody>
<tr>
<td>131000 MPa</td>
<td>0.3</td>
<td>8100 kg/m$^3$</td>
<td>1175 MPa</td>
</tr>
</tbody>
</table>

**Objectives of this work:** perform the deployment while
- minimising the maximum Von Mises stress $\sigma_{\text{VM max}}$
- minimising the maximum amplitude motion $d_{\text{max}}$

by the means of an optimisation procedure.
**PARAMETRIC STUDIES - THICKNESS**

With \( R = 20 \, mm \) and \( \alpha = 90^\circ \).

If \( t \nearrow \):

- \( M_{\text{max}} \nearrow \)
- \( \theta_{\text{max}} \nearrow \)
- \( M^* \nearrow \)
- \( \Delta E \nearrow \)
- \( \sigma_{\text{max}}^{VM} \nearrow \)
PARAMETRIC STUDIES - RADIUS

With $t = 0.1\ mm$ and $w = 28.28\ mm$.

If $R \uparrow$ and $\alpha \downarrow$:

- $M_{\text{max}} \downarrow$
- $\theta_{\text{max}} \uparrow$
- $M^* \downarrow$
- $\Delta E \downarrow$
- $\sigma_{\text{VM}} \downarrow$
Optimisation procedure performed on one tape spring with half the reflector mass (symmetric system).

Confirmation for the complete hinge (two tape springs) *a posteriori*. 
Optimisation - Model description

Optimisation problem:

$$\min_{x} f(x) \text{ such that } \begin{cases} c(x) \leq 0 \\ lb \leq x \leq ub \end{cases}$$

Nonlinear inequality constraints:

$$c_1 = w(\alpha, R) - w_{\text{max}} \leq 0$$
$$c_2 = h(\alpha, R) - h_{\text{max}} \leq 0$$

with $w_{\text{max}} = 30 \text{ mm}$ and $h_{\text{max}} = 15 \text{ mm}$

Lower and upper bounds:

<table>
<thead>
<tr>
<th></th>
<th>$t[\text{mm}]$</th>
<th>$R[\text{mm}]$</th>
<th>$\alpha[\text{rad}]$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$lb$</td>
<td>0.08</td>
<td>10</td>
<td>$\pi/3$</td>
</tr>
<tr>
<td>$ub$</td>
<td>0.25</td>
<td>32.5</td>
<td>$3\pi/4$</td>
</tr>
</tbody>
</table>
**OPTIMISATION - MINIMISATION OF $\sigma_{\text{max}}^{VM}$**

**Results:**

<table>
<thead>
<tr>
<th></th>
<th>$t$</th>
<th>$R$</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial geometry</td>
<td>0.08 mm</td>
<td>30 mm</td>
<td>$\pi/3$ rad</td>
</tr>
<tr>
<td>Optimised geometry</td>
<td>0.08 mm</td>
<td>19.07 mm</td>
<td>$\pi/3$ rad</td>
</tr>
</tbody>
</table>

$\sigma_{\text{max}}^{VM} = 666.25 \text{ MPa} < \sigma_y \quad d_{\text{max}} = 53.92 \text{ mm}$
OPTIMISATION - MINIMISATION OF $d_{\text{max}}$

Results:

<table>
<thead>
<tr>
<th></th>
<th>$t$</th>
<th>$R$</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial geometry</td>
<td>0.1 $mm$</td>
<td>15 $mm$</td>
<td>$\pi/2$ rad</td>
</tr>
<tr>
<td>Optimised geometry</td>
<td>0.244 $mm$</td>
<td>29.68 $mm$</td>
<td>1.0588 rad</td>
</tr>
</tbody>
</table>

$\sigma_{\text{max}}^{VM} = 1856 \text{ MPa} > \sigma_y$  \hspace{1cm} $d_{\text{max}} = 51.26 \text{ mm}$
OPTIMISATION - MINIMISATION OF $\sigma_{\text{max}}^{\text{VM}}$ AND $d_{\text{max}}$

Objective function: $f(x) = w_1\sigma_{\text{max}}^{\text{VM}} + w_2d_{\text{max}}$

Results:

<table>
<thead>
<tr>
<th></th>
<th>$t$</th>
<th>$R$</th>
<th>$\alpha$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial geometry</td>
<td>0.08 mm</td>
<td>10 mm</td>
<td>$\pi/3$ rad</td>
</tr>
<tr>
<td>Optimised geometry</td>
<td>0.0804 mm</td>
<td>30 mm</td>
<td>$\pi/3$ rad</td>
</tr>
</tbody>
</table>

$\sigma_{\text{max}}^{\text{VM}} = 877.75$ MPa $< \sigma_y$

$d_{\text{max}} = 52.08$ mm
Deployment of the reflector

Complete finite element model:
DEPLOYMENT OF THE REFLECTOR

Results:

\[ \sigma_{\text{VM},1TS}^{\text{max}} = 877 \text{ MPa} \quad \sigma_{\text{VM},2TS}^{\text{max}} = 866 \text{ MPa} \]

Validation of the optimisation procedure performed on a single tape spring.
DEPLOYMENT OF THE REFLECTOR

VIDEO
CONCLUSIONS

- Exploitation of tape springs to deploy reflectors.
- Parametric studies on the impact of the geometry.
- Optimisation procedure to minimise $\sigma_{\text{VM}}^{\text{max}}$ and/or $d_{\text{max}}$ on a single tape spring.
- Validation of the procedure for the complete hinge.

Perspectives:

- Material properties as design variables.
- Other orientations of the tape springs.
- Relevance of minimising $d_{\text{max}}$?

<table>
<thead>
<tr>
<th>$d_{\text{max}}$</th>
<th>$\min \sigma_{\text{VM}}^{\text{max}}$</th>
<th>$\min d_{\text{max}}$</th>
<th>$\min (w_1 \sigma_{\text{VM}}^{\text{max}} + w_2 d_{\text{max}})$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>53.92 mm</td>
<td>51.26 mm</td>
<td>52.08 mm</td>
</tr>
</tbody>
</table>
Thank you for your attention

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