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

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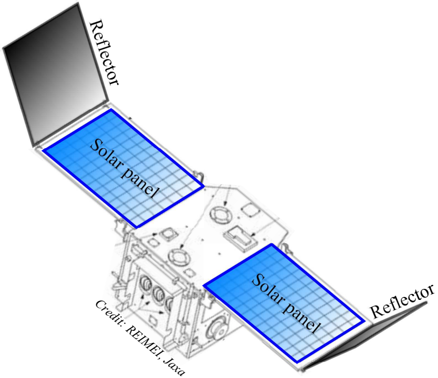
OUTLINE

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.

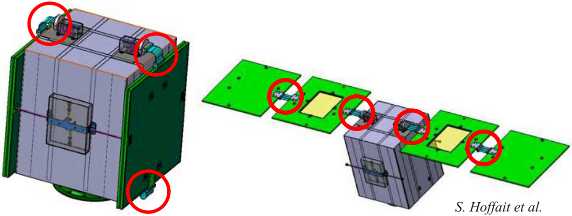


In this work: use of tape springs to deploy reflectors.

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



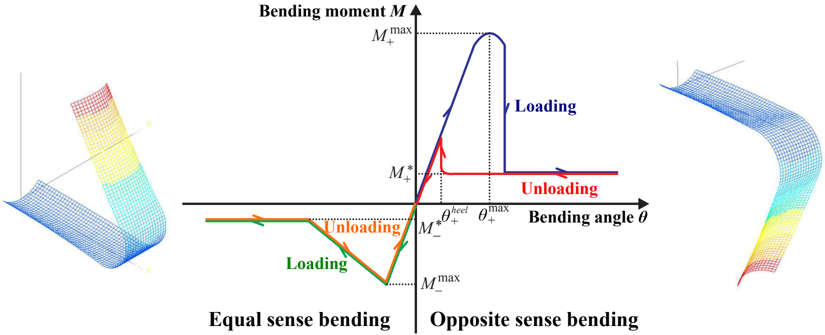
S. Hoffait et al.

⇒ Valuable components for **space applications**.

INTRODUCTION - TAPE SPRINGS

Mechanical behaviour:

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



Definition of the problem

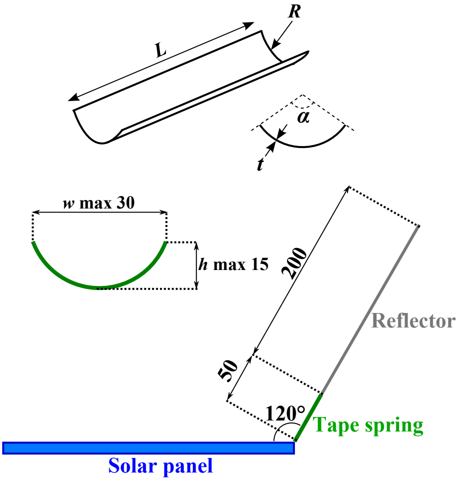
Folded configuration: reflector folded on the top of the solar panel considered as clamped.

Deployed configuration: 120°.

Fixed parameters:

- Reflector: $200 \times 200\ mm^2$, $m = 0.4\ kg$
- **Two** tape springs: $L = 50\ mm$
- Opposite sense

Design variables: t, R, α with $w \leq 30\ mm, h \leq 15\ mm$



DEFINITION OF THE PROBLEM

Material: beryllium copper

E	ν	ρ	σ_y
131000 MPa	0.3	8100 kg/m^3	1175 MPa

Objectives of this work: perform the deployment while

- minimising the maximum Von Mises stress $\sigma_{\max}^{VM}$
- minimising the maximum amplitude motion $d_{\max}$

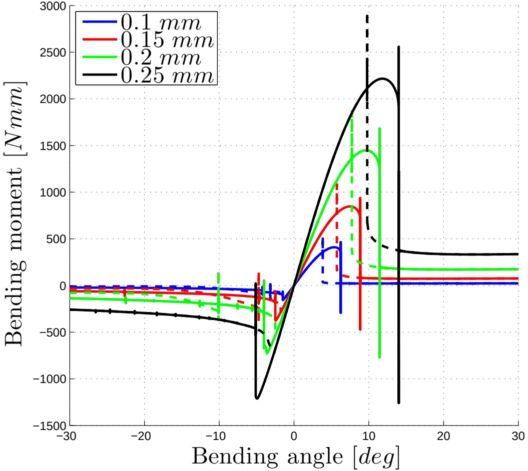
by the means of an optimisation procedure.

PARAMETRIC STUDIES - THICKNESS

With $R = 20\ mm$ and $\alpha = 90°$.

If $t \nearrow$:

- $M^{\max} \nearrow$
- $\theta^{\max} \nearrow$
- $M^{*} \nearrow$
- $\Delta E \nearrow$
- $\sigma_{\max}^{VM} \nearrow$

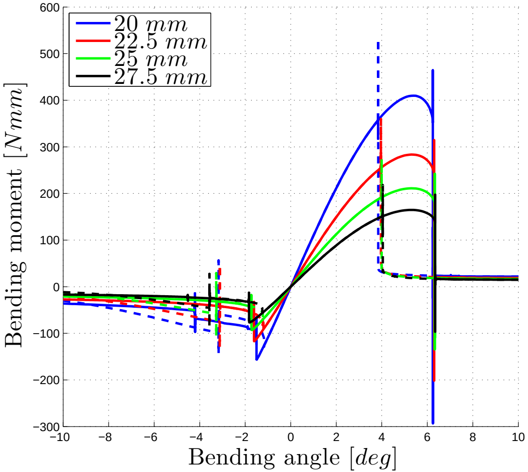


PARAMETRIC STUDIES - RADIUS

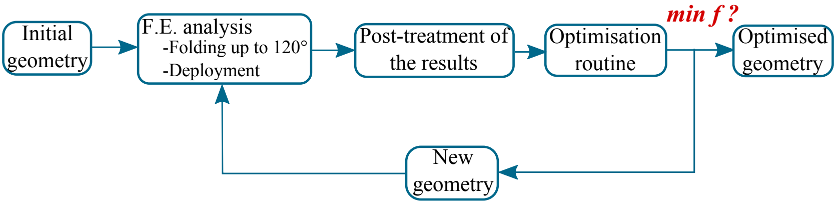
With $t = 0.1\ mm$ and $w = 28.28\ mm$.

If $R \nearrow$ and $\alpha \searrow$:

- $M^{\max} \searrow$
- $\theta^{\max} \nearrow$
- $M^{*} \searrow$
- $\Delta E \searrow$
- $\sigma^{VM}_{\max} \searrow$



OPTIMISATION - MODEL DESCRIPTION



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:

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

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

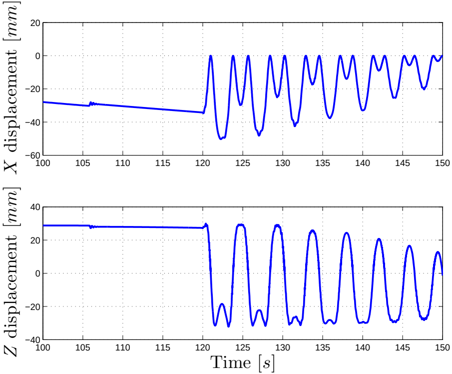
Lower and upper bounds:

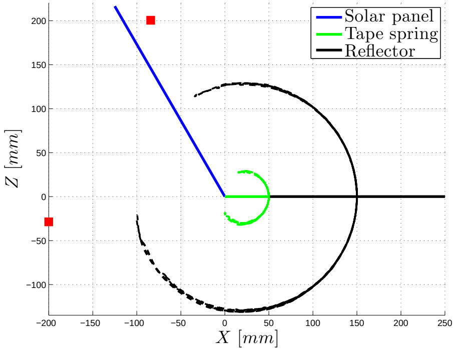
	$t[mm]$	$R[mm]$	$\alpha[rad]$
lb	0.08	10	$\pi/3$
ub	0.25	32.5	$3\pi/4$

OPTIMISATION - MINIMISATION OF $\sigma_{\max}^{VM}$

Results:

	t	R	α
Initial geometry	$0.08\ mm$	$30\ mm$	$\pi/3\ rad$
Optimised geometry	$0.08\ mm$	$19.07\ mm$	$\pi/3\ rad$



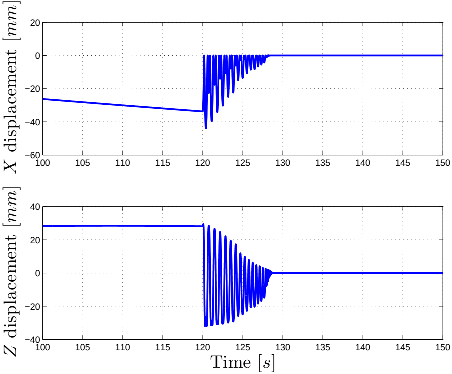


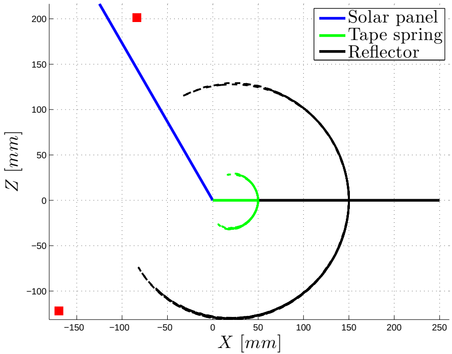
$$\sigma_{\max}^{VM} = 666.25\ MPa < \sigma_y \qquad d_{\max} = 53.92\ mm$$

Optimisation - Minimisation of $d_{\max}$

Results:

	t	R	α
Initial geometry	$0.1\ mm$	$15\ mm$	$\pi/2\ rad$
Optimised geometry	$0.244\ mm$	$29.68\ mm$	$1.0588\ rad$





$\sigma_{\max}^{VM} = 1856\ MPa > \sigma_y \qquad d_{\max} = 51.26\ mm$

OPTIMISATION - MINIMISATION OF $\sigma_{\max}^{VM}$ AND $d_{\max}$

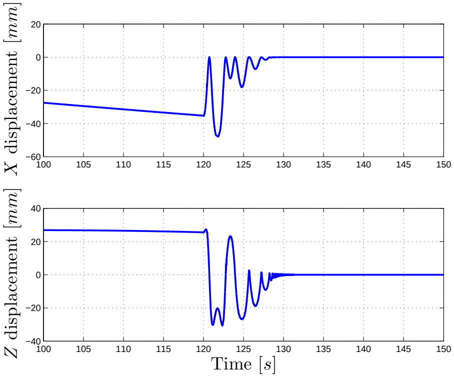
Objective function: $f(x) = w_1 \sigma_{\max}^{VM} + w_2 d_{\max}$

Results:

	t	R	α
Initial geometry	$0.08\ mm$	$10\ mm$	$\pi/3\ rad$
Optimised geometry	$0.0804\ mm$	$30\ mm$	$\pi/3\ rad$

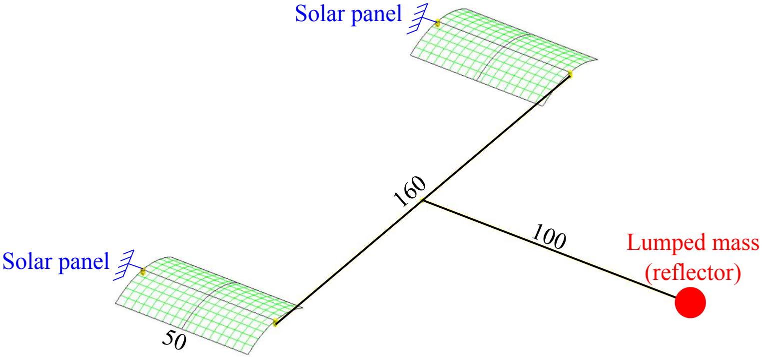
$$\sigma_{\max}^{VM} = 877.75\ MPa \ < \sigma_y$$

$$d_{\max} = 52.08\ mm$$



DEPLOYMENT OF THE REFLECTOR

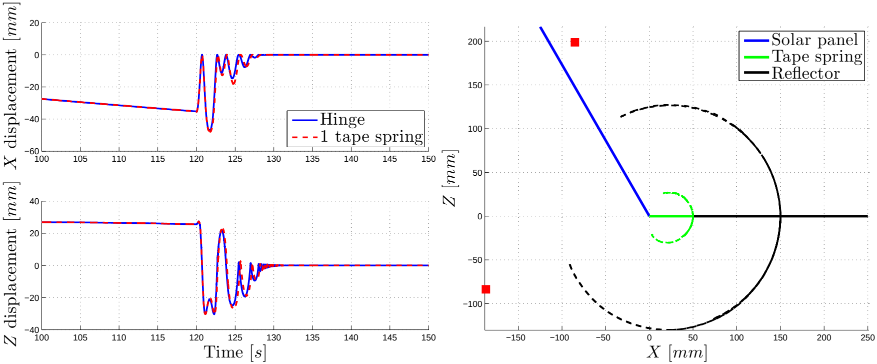
Complete finite element model:



DEPLOYMENT OF THE REFLECTOR

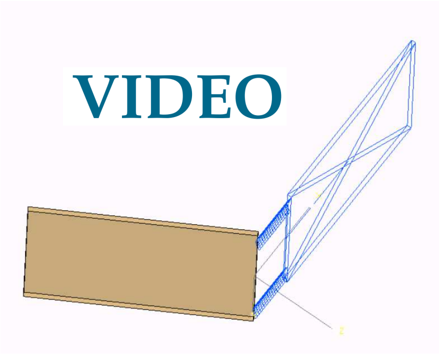
Results:

$$\sigma^{VM}_{\max,1TS} = 877\ MPa \qquad \sigma^{VM}_{\max,2TS} = 866\ MPa$$



Validation of the optimisation procedure performed on a single tape spring.

DEPLOYMENT OF THE REFLECTOR



Conclusions

- Exploitation of tape springs to deploy reflectors.
- Parametric studies on the impact of the geometry.
- Optimisation procedure to minimise $\sigma_{\max}^{VM}$ and/or $d_{\max}$ 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 $d_{\max}$?

	$\min \sigma_{\max}^{VM}$	$\min d_{\max}$	$\min(w_1\sigma_{\max}^{VM} + w_2 d_{\max})$
$d_{\max}$	53.92 mm	51.26 mm	52.08 mm

THANK YOU FOR YOUR ATTENTION

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