Experimental Validation of Structural Damping Models for Tape Springs

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Outline

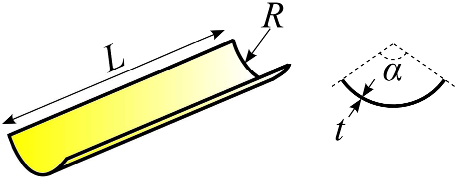

GPM Core Observatory satellite (Credit: NASA)

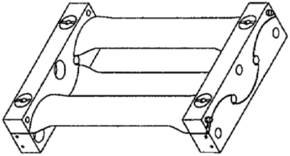
TAPE SPRINGS - DEFINITION

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

Known in the everyday life as Carpenter or measured tapes.

Geometry:



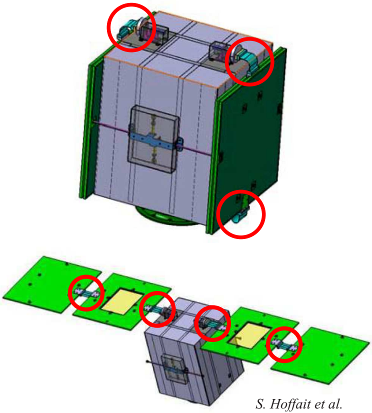


Credit: 01dB-Metravib & CNES

TAPE SPRINGS - ASSETS

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

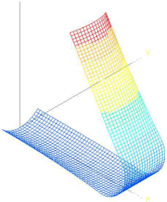
⇒ Valuable components for **space applications**.

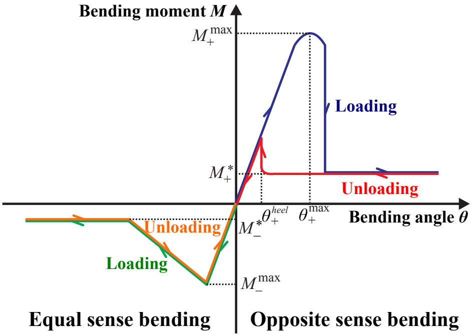


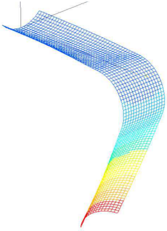
S. Hoffait et al.

TAPE SPRINGS - MECHANICAL BEHAVIOUR

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

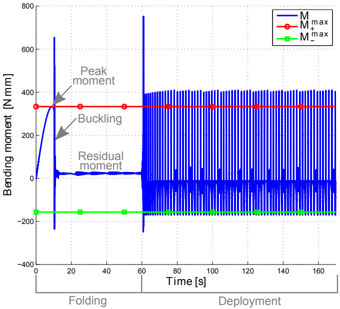




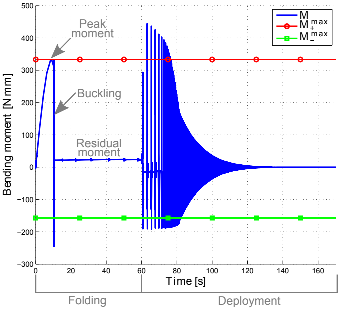


TAPE SPRINGS - PREVIOUS RESULTS

Context: Impact of the structural and numerical dampings in FEM analyses (Dewalque, Rochus, Brüls, *Importance of structural damping in the dynamic analysis of compliant deployable structures*, Acta Astronautica 2015)



Without structural damping



With structural damping

Conclusions:

- Numerical damping for the convergence of the solver
- Structural damping to capture the physical behaviour

Objectives

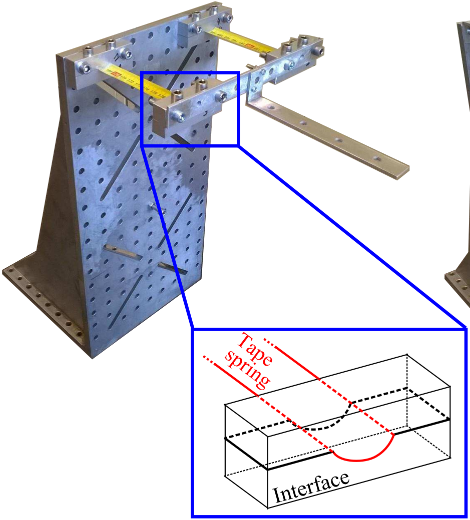
Based on an experimental set-up:

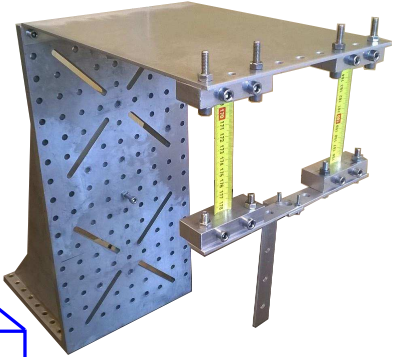
- Quantify the characteristics of the tape springs (quasi-static tests)
- Perform deployments (dynamic tests - large amplitudes)
- Characterise the structural damping (dynamic tests - small amplitudes)
- Correlate the finite element model

in an environment affected by gravity.

Experimental set-up

Horizontal configuration: **Vertical configuration:**



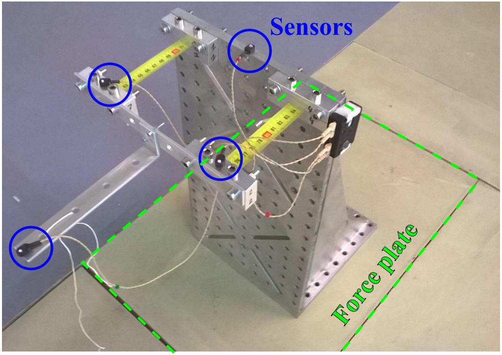


EXPERIMENTAL SET-UP

Measuring equipment:

- Force plate (*Kistler*)
- Motion sensors (*Codamotion*)

In the laboratory of human motion analysis (LAMH, ULg, Belgium).



EXPERIMENTAL SET-UP

Geometry and material of the tape springs:

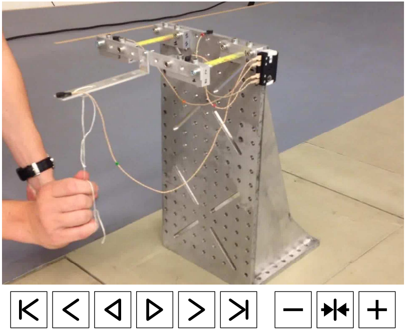
Length	Thickness	Subtended angle	Radius
100 mm	0.13 mm	1.219 rad	15.545 mm

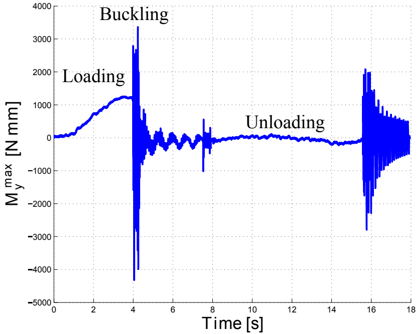
Young's modulus	Poisson's ratio	Density
$210,000$ MPa	0.3	$7,850$ kg/m^3

Uncertainties on the dimensions and the material properties.

Quasi-static tests

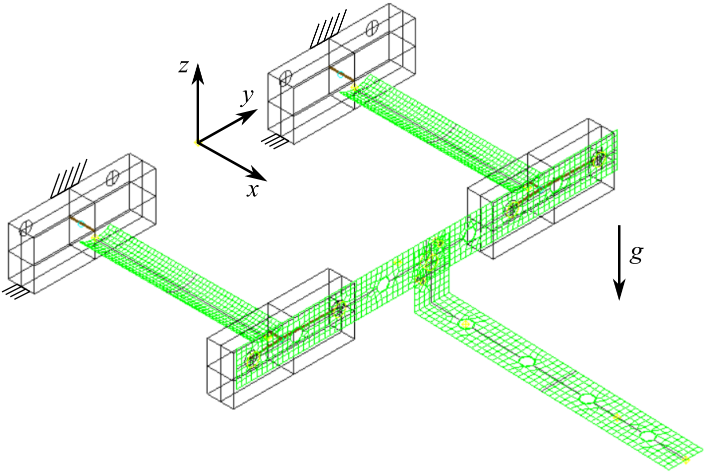
On the horizontal configuration, a vertical force is applied on the dummy panel:





QUASI-STATIC TESTS

Quasi-static finite element model:



Quasi-static tests

Results:

	Mean exp. value	FEM results	Diff. wrt. FEM
$F_z^{\max}$	3.33 N	4.13 N	19.52 %
$\theta_+^{\max}$	11.54°	11.84°	2.51 %
$M_y^{\max}$	1141.8 Nmm	980.6 Nmm	16.44 %

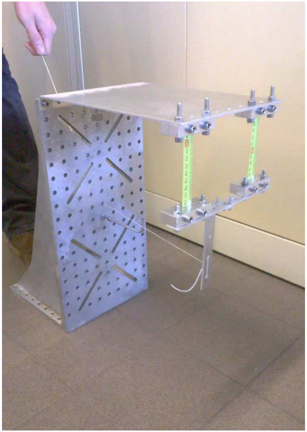
Reasonable results for such nonlinear tests performed manually on our first set-up.

Update of the FEM:

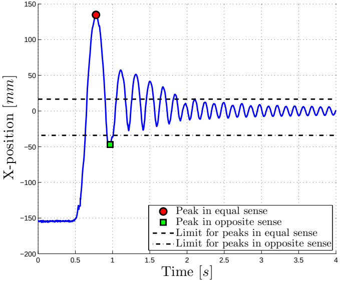
- Thickness: 0.15 mm
- Young's modulus: 205,000 MPa

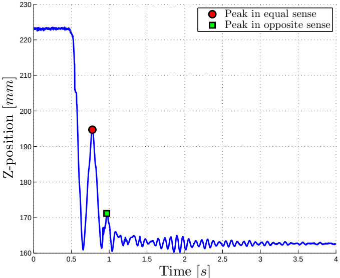
Dynamic tests

On the vertical configuration, folding up to an angle of $\sim 50°$, then deployment:



Limited lateral displacements

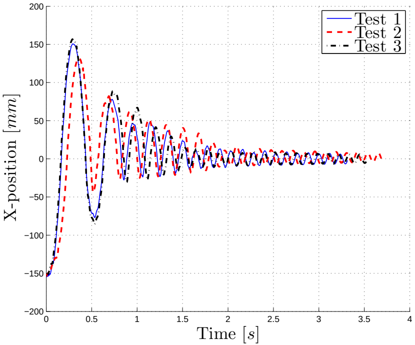




DYNAMIC TESTS

Complexity of the experimental tests:

- Vibration of the plate
- Repeatability

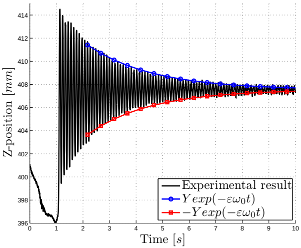


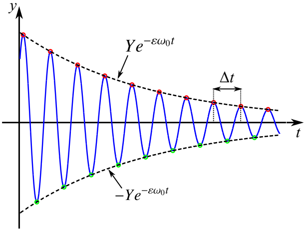
- Plastic deformations in the tape springs

Dynamic tests

Identification of the structural damping:

- Sources of damping: **tape springs**, connexions, other flexible parts, air resistance, acoustic effects
- Small amplitude vibration tests ⇒ linear dynamic response



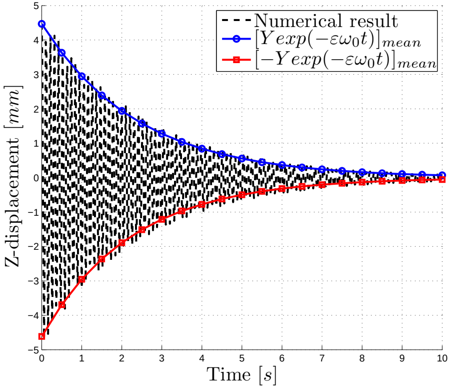


- Hypothesis: motion dominated by the first bending mode ⇒ exponential decay
- Mean experimental structural damping: $\varepsilon = 0.65\ \%$

DYNAMIC TESTS

Correlation of the FEM: (On the horizontal configuration)

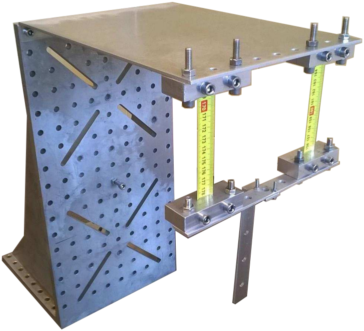
- Structural damping represented by a Kelvin-Voigt model based on a single viscosity coefficient

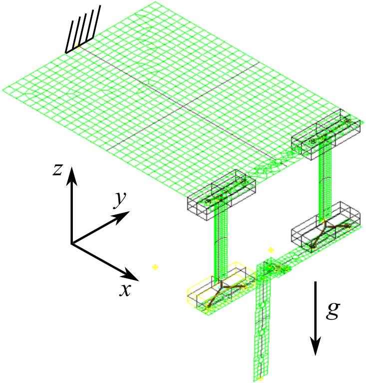


Results	ε	Frequency
Exp.	0.65 %	9.73 Hz
Num.	0.645 %	9.59 Hz

Dynamic tests

Dynamic finite element model:

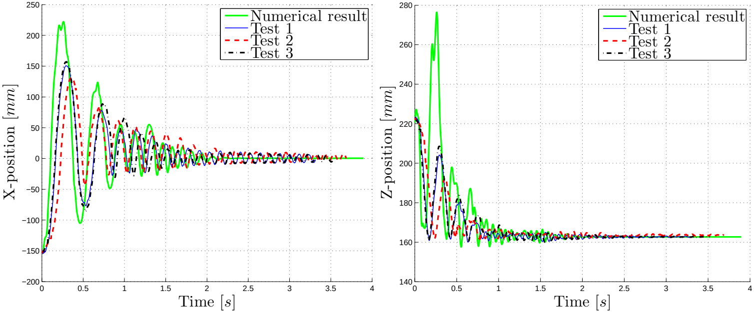




DYNAMIC TESTS

Correlation of the FEM:

- Large amplitude motion



Fair correlation for the oscillation frequency, but poor on the amplitudes.

Conclusions

- Building of an experimental set-up
- Limited lateral displacements
- Validation of the measuring equipment
- Proposition of a first measurement methodology
- Good correlation of the quasi-static behaviour
- Fair correlation on the frequency for dynamic tests
- Damping of the dynamic behaviour too complex to be captured by a single viscosity coefficient model

Perspectives:

- Implementation of more complex models in the FEM
- Improvement of the experimental set-up

THANK YOU FOR YOUR ATTENTION

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