Experimental characterisation of tape spring nonlinear compliant mechanisms

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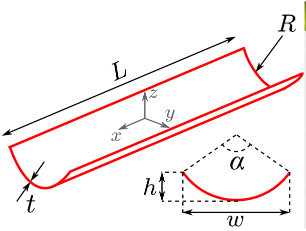
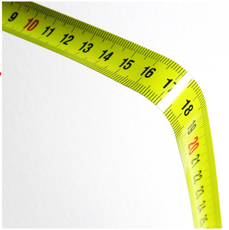
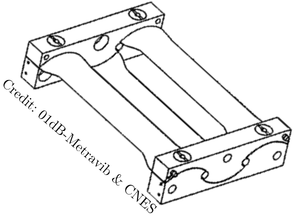
Outline

INTRODUCTION - TAPE SPRINGS

Definition: Thin strips curved along their width. These compliant mechanisms can be used in replacement of common kinematic joints to perform autonomous deployments.





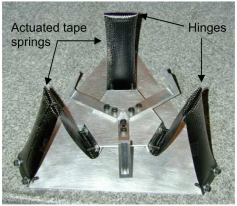


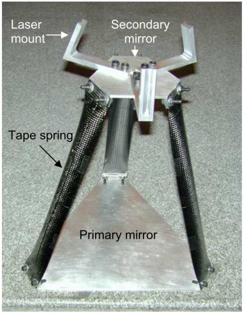
Main applications: deployment of solar panels, reflectors, antennas, masts... on satellites

INTRODUCTION - TAPE SPRINGS

Assets:

- Elastic deformation
- Passive and self-actuated deployment
- No lubricant
- Self-locking in deployed configuration
- Possibilities of failure limited
- Versatility



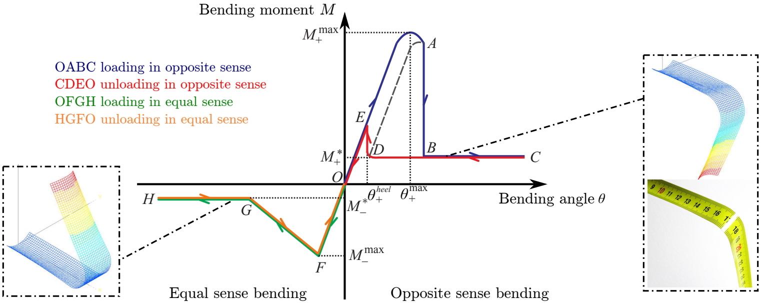


Credit: Black, Whetzal, deBlonk, Massarello (2006)

INTRODUCTION - TAPE SPRINGS

Complex phenomena:

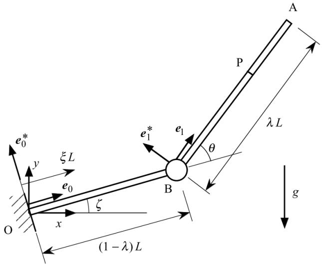
- Highly nonlinear mechanical behaviour
- Dependency to the sense of bending
- Buckling
- Hysteresis
- Shocks
- Large variations in the stiffness



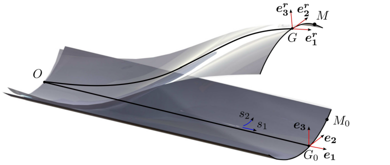
INTRODUCTION - MODELS

Analytical models:

Pioneers: Wüst (1954), Rimrott (1970), Mansfield (1973)



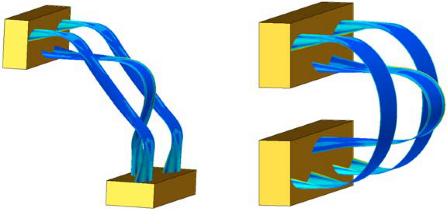
Credit: Seffen, Pellegrino (1999)



Credit: Guinot, Bourgeois, Cochelin, Blanchard (2012)

INTRODUCTION - MODELS

Finite element models:

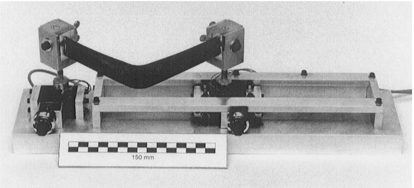


Credit: Hoffait et al. (2010)

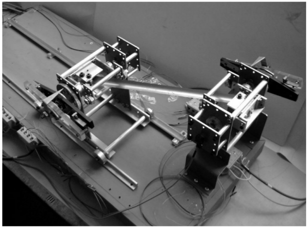
Credit: Soykasap (2006)

INTRODUCTION - MODELS

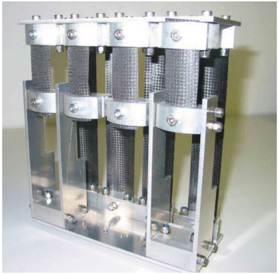
Experimental set-ups:



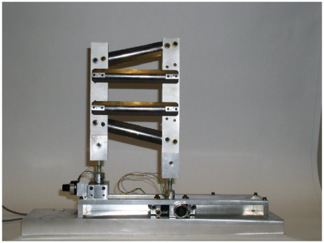
Credit: Seffen, You, Pellegrino (2000)



Credit: Walker, Aglietti (2006)



Credit: Boesch et al. (2008)



Credit: Soykasap (2006)

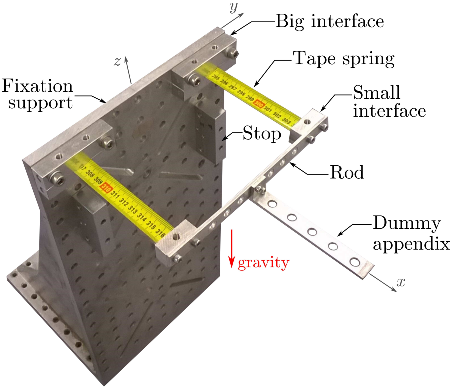
Introduction - Objectives

To validate **nonlinear dynamic FE models** of tape springs with an appropriate representation of the **structural damping**

Steps:

- Design of an **experimental set-up** to collect data on 3D deployment motions
- Assessment of the **reproducibility** of the tests
- Identification of the model parameters by the means of **specific tests**
- **Comparison** between the experimental and numerical results

Experimental set-up



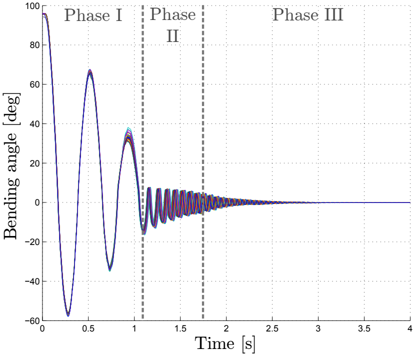
Acquisition equipment:

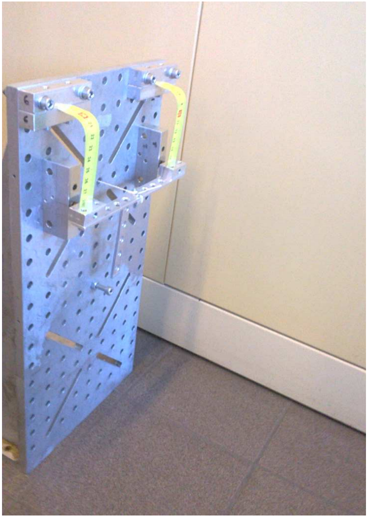
- 3D motion analysis system (Codamotion)
- Triangulation of active markers (precision $\sim$ 0.3 mm)

Laboratoire Analyse Mouvement Humain

EXPERIMENTAL TESTS

Initial folding in **opposite sense**:





EXPERIMENTAL TESTS

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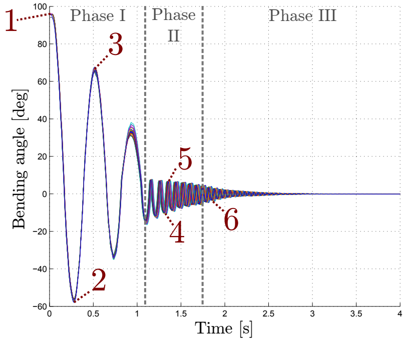
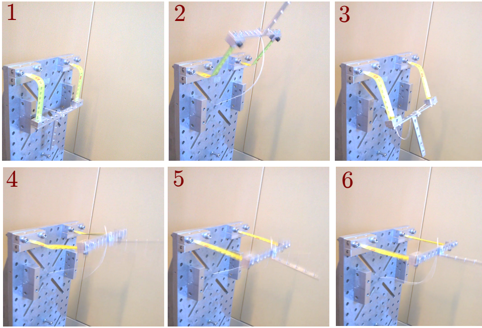
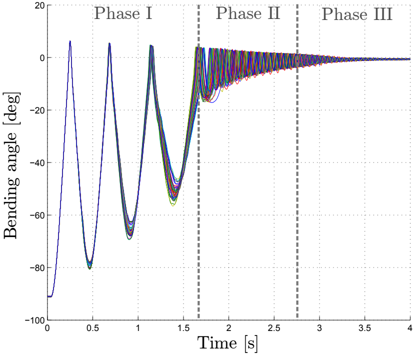




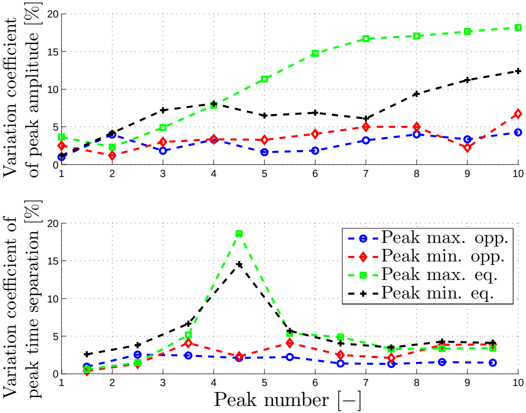
EXPERIMENTAL TESTS

Initial folding in **equal sense**:



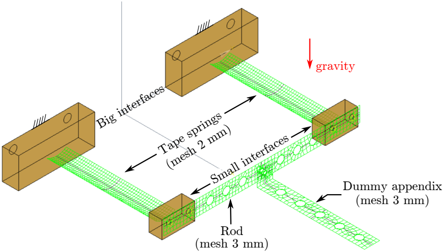
EXPERIMENTAL TESTS

Reproducibility:



Finite element model

Modelling assumptions:



Unknown parameters:

Young's modulus, thickness, structural damping

- Shells for tape springs, rod and dummy appendix
- Rigid interfaces
- Big interfaces clamped
- Structural damping in the tape springs
- Nonlinear dynamic analyses
- Generalised-α method
- Low numerical damping
- Automatic time stepping procedure
- SAMCEF software

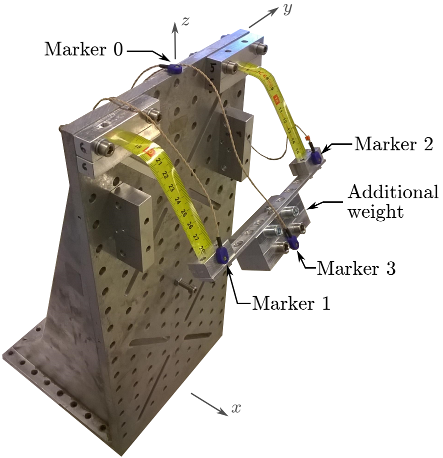
FINITE ELEMENT MODEL

Identification of the Young's modulus E and the thickness t:

- Experimental static test focusing on the post-buckling behaviour
- Optimisation procedure
- Results:

E [MPa]	t [mm]
151760	0.138

$\Delta^{exp-num} < 5\ \%$



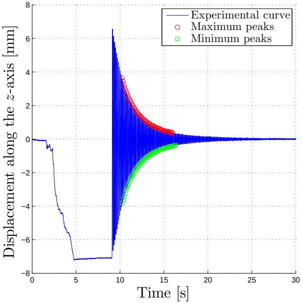
FINITE ELEMENT MODEL

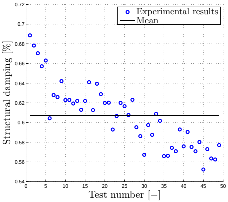
Identification of the structural damping ε:

- Small amplitude vibration tests (no buckling)
- Represented in the FE model by a Kelvin-Voigt model
- Results:

	Exp.	Num.	Δ
ε	0.509 %	0.505 %	0.79 %
Δt	0.100 s	0.110 s	10 %

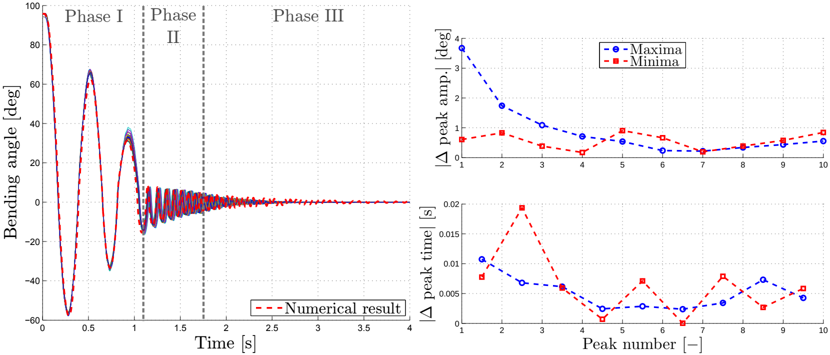
- Large variations of ε during the experimental tests





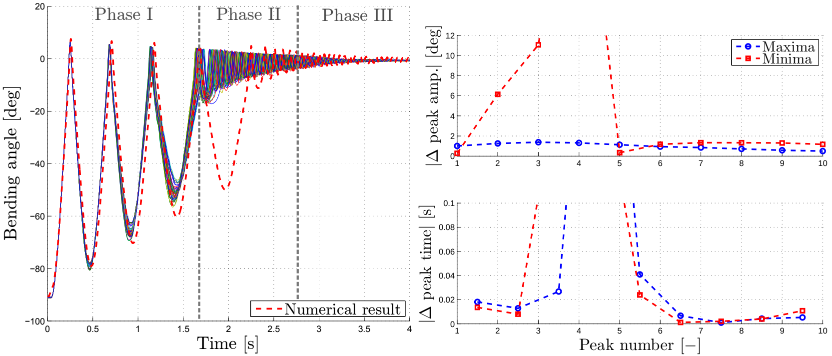
VALIDATION OF THE FE MODEL

Comparison with the exp. tests: Initial folding in **opposite sense**



VALIDATION OF THE FE MODEL

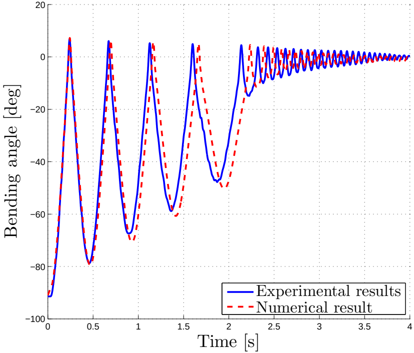
Comparison with the exp. tests: Initial folding in **equal sense**



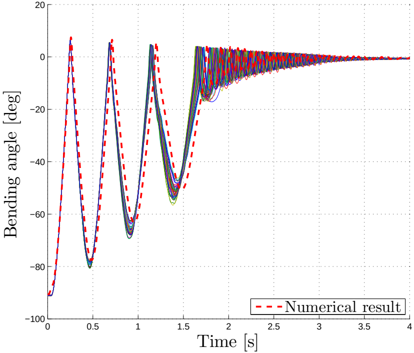
VALIDATION OF THE FE MODEL

Comparison with the exp. tests: Initial folding in **equal sense**

Slightly disturbed exp. set-up



Slightly disturbed FE model



Conclusions

- Experimental data acquired by the means of a **3D motion analysis system**
- **Good reproducibility** of the experimental tests
- **Nonlinear dynamic motions** divided in three phases based on the folds, frequency and damping
- Identification of the parameters of the FE model based on **specific tests** (static and small vibrations)
- **Good prediction** of the deployments in opposite sense
- **Sensitivity** of the set-up and the model to the initial conditions in equal sense

Conclusions

Perspectives:

- Other configurations of the tape springs
- Other materials for the tape springs
- Large 3D motions with more complex initial foldings
- Simulate the behaviour under different conditions (vacuum, zero gravity)

THANK YOU FOR YOUR ATTENTION

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fnrs FREEDOM TO RESEARCH