Design of an experimental set-up to analyse compliant mechanisms used for the deployment of a panel

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OUTLINE

INTRODUCTION

EXPERIMENTAL SET-UP

FINITE ELEMENT MODEL

IDENTIFICATION OF THE PARAMETERS

VALIDATION OF THE FE MODEL

CONCLUSIONS
**INTRODUCTION - TAPE SPRINGS**

**Definition:** Thin strips curved along their width used as compliant mechanisms in replacement of common kinematic joints.

**Space applications:** deployment of solar panels, reflectors, antennas, masts...
Introduction - Tape Springs

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

**Complexity:**
- Highly nonlinear
- Different senses of bending
- Buckling
- Hysteresis
Introduction - Objectives

▶ To design an experimental set-up

▶ To collect experimental data on tape springs

▶ To perform a large variety of tests (quasi-static, dynamic, small amplitude, large amplitude, ...)

▶ To evaluate the parameters required to develop a finite element model

▶ To correlate finite element models with the experimental results
EXPERIMENTAL SET-UP

Constraints:
Despite the presence of the gravity field,
- No buckling under its own weight
- Passive deployment starting from a downwards folded configuration
**Experimental Set-up**

**Acquisition equipment:**
- 3D motion analysis system (Codamotion)
- Acquisition frequency: 800 Hz
- Triangulation of active markers (precision $\sim 0.3 \text{ mm}$)
- Force plate under the support (Kistler)
**EXPERIMENTAL SET-UP**

**Deployment tests:**
Initial downwards folding in opposite sense
EXPERIMENTAL SET-UP

**Positions:** (superposition of 50 curves)

- Displacement along the $x$-axis [mm]
- Displacement along the $z$-axis [mm]
- Vertical force [N]

**Vertical force:**
**Deployment tests**

**Reproducibility of the experimental results:** for 170 tests with 4 pairs of tape springs

*On the positions:*

- Relative SD. $< 1\%$ for the peak amplitudes

- Relative SD. $\uparrow$ for the peak times
**FINITE ELEMENT MODEL**

- Shells for tape springs and rod
- Rigid interfaces
- Big interfaces clamped (fixation support not represented)
- Structural damping in the tape springs
- Nonlinear dynamic analyses
- Generalised-$\alpha$ method
- Low numerical damping
- Automatic time stepping procedure
- SAMCEF software
FINITE ELEMENT MODEL

Unknown parameters:

- Thickness $t$ and Young’s modulus $E$ of the tape springs

**Why?**
- Small thickness ($\sim 0.14$ mm)
- Tape springs cut out from a common measuring tape
- Composite (metallic layer + coating + plastic)
- Non uniformity

**Strategy of identification:** Quasi-static three points bending tests
**FINITE ELEMENT MODEL**

**Unknown parameters:**

- Structural damping $\varepsilon$

**Why?**

- Various sources (material, connections, air resistance, acoustic effects, ...)
- Important parameter to capture the physical behaviour

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**Strategy of identification:** Small amplitude vibration tests

*Source: Dewulque, Rochus, Bruls, Importance of structural damping in the dynamic analysis of compliant deployable structures, Acta Astronautica 2015*
IDENTIFICATION OF $t$ AND $E$

Three points bending tests:

Use of an optimisation algorithm coupled to a FE model to determine $t$ and $E$ fitting the experimental results

Exp. relative SD. $< 5\%$

$\Delta(exp - num) < 14\%$
Identification of the Structural Damping

Small amplitude vibration tests:

Hypothesis: Exponential decay of the oscillations $Z \exp(-\varepsilon \omega t)$

$\Rightarrow$ Can be represented by a Kelvin-Voigt model in the FE model
**IDENTIFICATION OF \( \varepsilon \)**

**Small amplitude vibration tests:** (510 tests in 11 sessions)

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<tr>
<th></th>
<th>Mean</th>
<th>Max. diff.</th>
<th>Relative SD.</th>
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<tr>
<td>( \varepsilon )</td>
<td>0.509 %</td>
<td>0.288 %</td>
<td>20.67 %</td>
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<tr>
<td>( \Delta t )</td>
<td>0.100 s</td>
<td>0.003 s</td>
<td>0.919 %</td>
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**Challenging measurements:**

- Sensitivity to the assembly procedure
- Non-uniformity of the samples cut out from the same measuring tape
- Thermal effects within a session of tests
**Validation of the FE model**

**Deployment tests:** comparison with the experimental results
VALIDATION OF THE FE MODEL

Deployment tests: comparison with the experimental results

Displacement along the x-axis [mm]

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<th>t exp− t num</th>
<th>max(t exp) [%]</th>
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Displacement along the z-axis [mm]

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<th>Peak max. x</th>
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Peak number [−]

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VALIDATION OF THE FE MODEL

Experimental

Numerical
CONCLUSIONS

- Design of an experimental set-up
- Acquisition of experimental data by the means of a 3D motion analysis system
- **Good reproducibility** of the deployment tests
- Identification of the FE parameters based on 3PBT and small vibrations (no use of the deployment tests)
- **Fair correlation** of the FE model ($\Delta < 15\%$)
- Good **basis for a prediction** of the behaviour in space environment
Conclusions

Perspectives:

▶ Perform experimental tests in equal sense
▶ Add markers on the set-up
▶ Improve the numerical model
  ▶ Investigate other damping models
  ▶ Represent the fixation support in the FE model
THANK YOU FOR YOUR ATTENTION

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