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NONLINEAR ANALYSIS OF TAPE SPRINGS: COMPARISON OF TWO GEOMETRICALLY EXACT FINITE ELEMENT FORMULATIONS

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Tape springs are widely used for the design of compliant mechanisms, whose motion results from the elastic deformation of structural components and not from a sliding motion between contact surfaces as in usual hinges or prismatic joints. In space applications, tape springs are used for the deployment of solar panels, antennas, telescopes and solar sails. Their behavior relies on the storage of elastic energy in a compact folded configuration and on the release of this energy during the deployment process to produce the desired motion. There is thus no need for actuators or external energy sources and the deployment can be achieved in a purely passive manner, which appears as a decisive advantage for the design of low-cost missions with small satellites or cubesats.

The mechanical behavior of a tape spring compliant structure can be quite complex and nonlinear involving buckling, hysteresis and self-locking phenomena. In some cases, the structure exhibits a multi-stable behavior with an unstable path between extreme configurations. Even though the deformations often remain in the elastic regime, the geometric nonlinearities dominate the folding and deployment process. High-fidelity mechanical models are needed in order to get a detailed understanding of the deployment process, improve the design and predict the actual behavior in the space 0-g environment.

For example, the planar and quasi-static response of a single tape spring is presented in Figs. 1 and 2. The tape spring is clamped at one extremity and its rotation is imposed as a linear function of time at the other extremity. When the bending angle is close to 16 deg, the structure buckles, a fold appears in the middle of the tape spring, and the bending moment suddenly drops. In this example, the imposed bending motion is very slow so that the response is close to the static response excepted when the buckling occurs.

In this work, two finite element formalisms are studied for such nonlinear structural analyses. This first approach is based on a rather classical geometrically exact shell

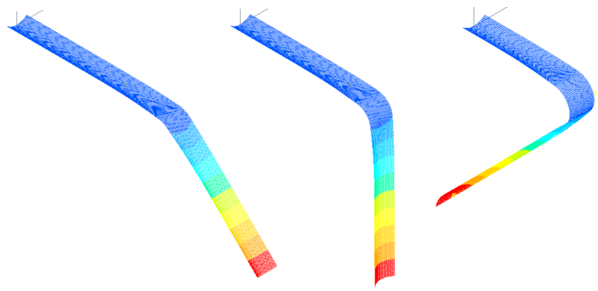

Figure 1: Bending of a curved tape spring (bending angles: 45°, 90° and 135°).

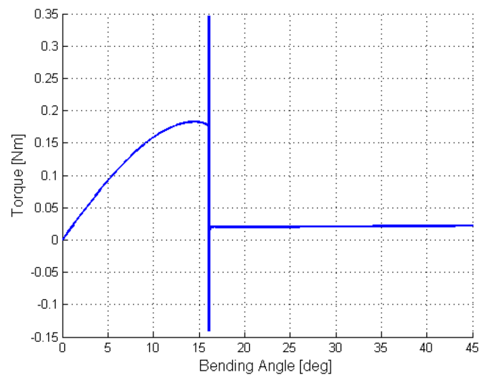

Figure 2: Evolution of the torque with respect to the bending angle.

formulation, which was used in [1]. The second approach is based on a more recent formulation on the special Euclidean group, which extends the work in [2] to shells. The comparison reveals that the two methods converge to the same results when the mesh is refined and that the second strategy significantly reduces the geometrical nonlinearity of the model with the main advantage that the stiffness matrix does not need to be updated at each iteration.

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