11th. World Congress on Computational Mechanics (WCCM XI)
5th. European Conference on Computational Mechanics (ECCM V)
6th. European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

A ROD MODEL WITH FLEXIBLE CROSS-SECTIONS FOR THE FOLDING AND DYNAMIC DEPLOYMENT OF TAPE-SPRINGS

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Key words: *Tape springs, Non-linear elastic rods, Folding, Dynamics, Bifurcations*

A tape spring is an elastic structure whose free-state geometrical form resembles a thin-walled beam with an open circular cross-section. Such structures are capable of forming localized folds, due to a complete flattening of the cross-section. Away from the folds, the tape spring remains straight and almost undeformed.

A carpenter's tape measure is a typical example of a tape-spring. Using it, one can easily experience the formation and motion of folds, the splitting of a fold into two, or the merging of two folds into one (Fig 1). The number and position of folds depend on the boundary conditions applied to the tape spring, and for a same set of boundary conditions, a tape spring can show several stable configurations. Thus, the modeling of such structures appears as quite challenging. It is shown in this work that the recently developed rod model with flexible cross-sections ([1], [3]) correctly accounts for the complex behavior of tape springs, such as 2D and 3D foldings.

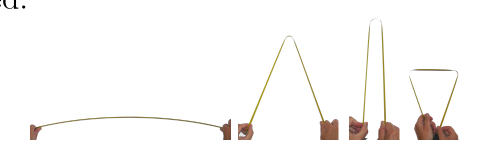

Figure 1: Folding of a carpenter's tape measure

Considering the tape as a thin-walled beam (Fig 2), the main originality of the model resides in the use of an Elastica kinematics to describe the important changes in the shape of the circular cross-section middle line with very few kinematic parameters : only one is required for the cross-section shape.

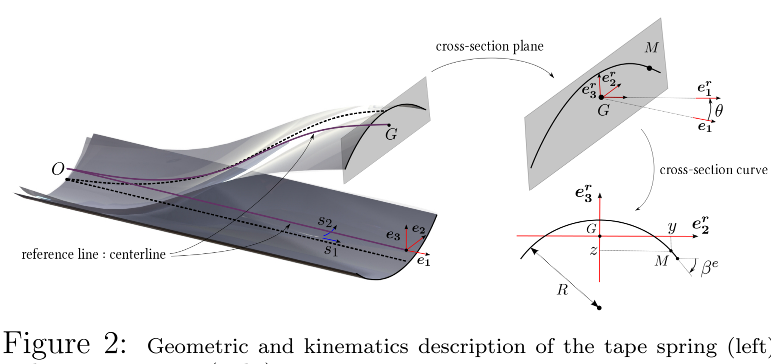

Figure 2: Geometric and kinematics description of the tape spring (left) and its cross-section (right)

In the 3D version of the model ([3]), a Vlassov kinematics accounts for out-of-plane deformation through torsional warping.
These kinematic hypotheses are introduced in the strain and kinetic energies of the shell in large displacements, large rotations and dynamics. The rod energetic model is obtained through integration over the cross-section of these energies and the Hamilton Principle is used in the finite element modeling software COMSOL ([4]), chosen for its ability to automatically differentiate expressions. It is shown in Fig 3 that the model is able to qualitatively and quantitatively account for a complex scenario of dynamic deployment in which a migration of the fold occurs.

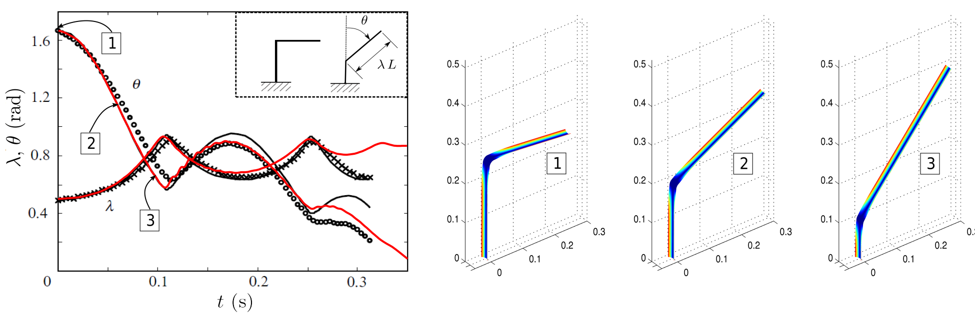

Figure 3: Numerical simulation of dynamic deployment of a folded tape spring. Left : Evolution of the fold angle θ and the length λ of the free straight part of the spring with respect to time. Crosses and circles : experimental results. Black solid lines : theoretical results from Seffen and Pellegrino ([2]). Red solid lines : results obtained with the model, with viscous damping. Right : Reconstructed deformed shapes of the tape during deployment.

Experimental and numerical simulations show that tape springs are very sensitive to imperfections. In this context, full static bifurcation diagrams are helpful to understand the overall behavior of a tape spring. Since COMSOL is not able to track all the possible solutions, a home-made modeling tool using the Matlab package MANLAB ([5]) has been developed to detect bifurcation points and follow all equilibrium branches, whether stable or unstable. This tool will be used to study the possible deployment scenarios of structures made of several tape springs.

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