Experimental Dynamics of Composite Bistable Cantilever Shells

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Summary
Bistable cantilever shells subjected to harmonic base excitation have been experimentally investigated with the aim of extending previous quasi-static studies [1] and characterizing their nonlinear dynamic behavior. The tested shells have rectangular planform and almost cylindrical shape. Their shorter edge, flattened by means of a specifically designed clamp, has been excited using an electrodynamic shaker. Sensors and dedicated interface electronics for forward and backward frequency sweeping and control have allowed the identification of the nonlinear resonance curves. Such curves describe the intrawell nonlinear dynamics around the stable equilibrium configurations of the tested shells and have clearly exhibited the expected softening behaviour. Moreover, the experimental campaign provided insights on the dynamic regimes enabling to trigger snap-through mechanisms.

Introduction

The possibility to design and manufacture bi- or multi-stable structures is interesting for both technological and scientific reasons. As an example, a bistable device consisting of a ferromagnetic cantilever elastic beam and two fixed magnets has been proposed in [2]; for such a system the bistability is the result of the interaction between the magnetic field yielded by the magnets and the beam. The authors found the occurrence of nonlinear phenomena, including chaos; in this case the bistability has been exploited to harvest energy from the beam motion. More complicated bistability or multistability systems are presented in the doctoral dissertation [3], where potential applications in aircraft and aerospace industries are suggested. A special class of cantilever composite shells exhibiting multi-stability has been presented by the authors in [1]. Finite element numerical simulations confirmed by experimental tests demonstrated the existence of two or four stable equilibrium configurations, depending on the shape of the natural stress-free configuration of the shell. While therein the research was limited to quasi-static analysis, in this contribution the aim is to perform experimental tests for characterizing the nonlinear dynamics of the multi-stable shells.

Tested composite shells and experimental setup

The manufactured shells are made of carbon-epoxy unidirectional eight-layers composite with stacking sequence [45/-45_2/45/-45/45_2/-45]. Each prototype has been manufactured using autoclave technology; we refer to [1] for all the details about the shell geometry and the constitutive properties. During the manufacturing process different moulds have been used to obtain the two shapes chosen for the prototypes. These latter have an almost cylindrical shape and differ only in length; we label A the longer shell, B the shorter. The natural stress-free configuration of A and B shells is shown in Figure 1. After flattening and clamping one of the shorter edges both shells turn out to be bi-stable, with I or C stable shape configurations (see reference [1]).
The shells are clamped into a special holder and then mounted on the electrodynamic shaker armature. The structure is then kinematically excited with the shaker controller set in sine mode with a constant acceleration of amplitude a_{shaher}. The excitation frequency *f(t)* has been swept forward and then backward and the shell response has been measured by a piezoelectric triaxial accelerometer (a_x,a_y, a_z). Based on the measured signals, the experimental resonance characteristics have been identified.

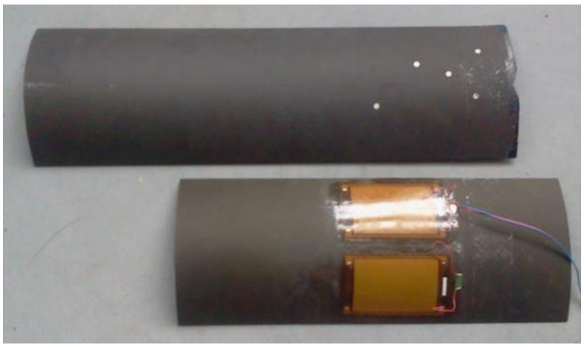

Figure 1: Shell shape before clamping, variant A and B.

Experimental results

The experimental results for the (longer) shell A are shown in Figure 2 for I (Figure 2 a) and C stable shapes (Figure 2b), respectively (accelerometer at the free end). For the I stable shape the softening effect is clearly visible: when incrementing the excitation amplitude the resonance is shifted towards lower frequencies. In contrast, for the C stable shape the resonance shifting is not so evident.

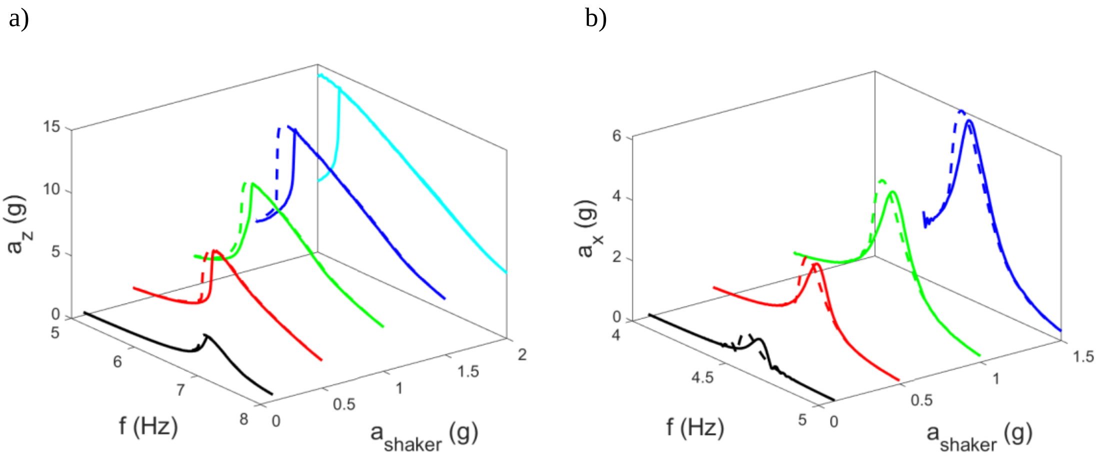

Figure 2: Resonance characteristics of A shell; a) I stable configuration, b) C stable configuration
solid line - frequency sweep forward, dashed line - frequency sweep backward

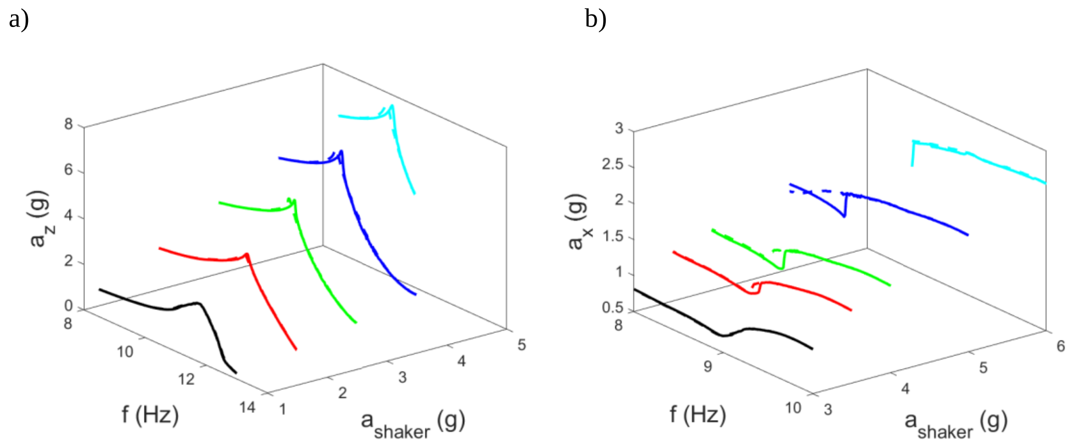

Figure 3: Resonance characteristics of B shell; a) I stable configuration, b) C stable configuration
solid line - frequency forward, dashed line - frequency backward

The experimental curves for the (shorter) shell B are shown in Figure 3 (accelerometer at the clamped end). As expected, the resonance frequencies of the shorter shell are higher than those of the longer shell. For example, the natural frequency of the I stable configuration is about 11 Hz for the shell B (Figure 3a) and about 7 Hz for the shell A (Figure 2a). In this case the softening effect is evident on both Figures 3a and 3b: for the shorter shell, as the excitation amplitude is increased, the resonance frequencies for both the I and C stable shapes are shifted towards lower values.

Conclusions

In this contribution the nonlinear dynamics of bi-stable composite shells has been experimentally investigated. The intrawell dynamics around the stable configurations has shown a softening behaviour for both the manufactured prototypes. While the snap-through phenomenon has not been found in the present experimental set-up, further on-going tests are devoted to trigger a shape jump between the I and C stable configurations. The obtained data will be used to validate numerical models as well as reduced order semi-analytical models.

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