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Resonant responses and chaotic dynamics of composite laminated circular cylindrical shell with membranes

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This paper is focused on the resonant responses and chaotic dynamics of a composite laminated circular cylindrical shell with radially pre-stretched membranes at both ends and clamped along a generatrix. Based on the two-degree-of-freedom non-autonomous nonlinear equations of this system, the method of multiple scales is employed to obtain the four-dimensional nonlinear averaged equation. The resonant case considered here is the primary parametric resonance-1/2 subharmonic resonance and 1:1 internal resonance. Corresponding to several selected parameters, the frequency-response curves are obtained. From the numerical results, we find that the hardening-spring-type behaviors and jump phenomena are exhibited. The jump phenomena also occur in the amplitude curves of the temperature parameter excitation. Moreover, it is found that the temperature parameter excitation, the coupling degree of two order modes and the detuning parameters can effect the nonlinear oscillations of this system. The periodic and chaotic motions of the composite laminated circular cylindrical shell clamped along a generatrix are demonstrated by the bifurcation diagrams, the maximum Lyapunov exponents, the phase portraits, the waveforms, the power spectrums and the Poincaré map. The temperature parameter excitation shows that the Pomeau-Manneville type intermittent chaos occur under the certain initial conditions. It is also found that there exist the twin phenomena between the Pomeau-Manneville type intermittent chaos and the period-doubling bifurcation.

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1. Introduction

The demand of ring truss antennas is generated due to the rapid development of the modern communication satellites. In order to save room for launching into space, the truss antennas should be designed foldable and deployable. The ring truss antenna is considered to be a reliable and promising scheme to realize its complete deployment [1–5]. After arriving at the predetermined orbit, the ring truss antenna can be fully deployed to form a circular cylindrical shell shape clamped by one beam along its generatrix and with the pre-tightening force meshes covered on both ends, as shown in Fig. 1.

The traditional numerical methods for the circular mesh antennas have a low credibility and lead to the huge amount of computation. However, engineers want to understand the nonlinear vibrations of the circular mesh antennas in a

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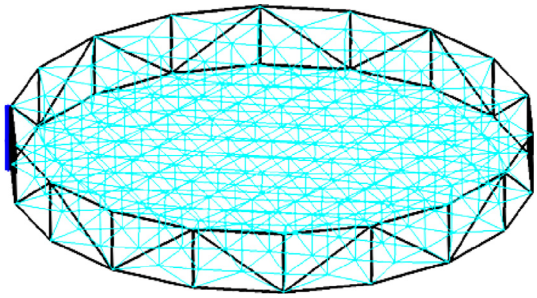

Fig. 1. The geometric model of the circular mesh antenna is shown.

macroscopic view through the theoretical analysis based on the equivalent continuous model. The main structure of the circular mesh antennas consists of two parts, namely the ring truss antenna and the three-way mesh. Firstly, the ring truss antenna is usually shaped as the circular shell with the repetitive beam-like lattice grids due to the actual applications in space environment. Secondly, it is not neglected that the double meshes are stretched in the ring truss antenna at both ends due to the function of the ring truss antenna. It is necessary to consider the coupling effects between the ring truss antenna and the meshes on the nonlinear oscillations of the ring truss antenna.

Zhang et al. [6,7] established a model of the continuum circular cylindrical shell clamped along one generatrix to substitute the ring truss structure with the repetitive beam-like lattice based on the equivalence principle. It is found that after the circular mesh antennas are deployed in the space environment, there exist four basic nonlinear oscillations including the radial breath nonlinear oscillations, the torsional, the bending and the rolling nonlinear oscillations around support beam. Based on the continuum circular cylindrical shell, Sun et al. [8] investigated the homoclinic bifurcations and the Shilnikov type multi-pulse chaotic dynamics by using the energy phase method and the existence of the Shilnikov type multi-pulse orbits was determined. Liu et al. [9] studied a three-way mesh structure of the ring truss antenna and obtained a dynamic model which is equivalent to a membrane via the energy equivalence principle. The validity of the equivalent model is verified by the finite element simulation.

Although the continuum circular cylindrical shell model [6,7] and the membrane model [9] have been given respectively, their researches only consider the ring truss antenna or three-way mesh structure. Liu et al. [10] simplified the circular mesh antenna to a composite laminated circular cylindrical shell with the membranes at both ends. They studied the nonlinear oscillations of this model in the case of 1:2 internal resonances and also found that the system exhibits the chaotic motions, as shown in Fig. 2. The new equivalent model is basically suitable to the real structure of the circular mesh antenna by considering the coupling effect of the ring truss and the meshes.

According to the recent discovered internal resonance relationship of the circular mesh antenna through the finite element analysis, this paper is devoted to the studies of the radial breath nonlinear oscillations about a composite laminated circular cylindrical shell with radial pre-stretched membranes at both ends in the case of 1:1 internal resonance.

Circular cylindrical shell structures have been widely used in civil engineering, mechanical engineering and aerospace and aeronautic engineering. The nonlinear shell theories have been studied for a century [11,12]. Donnell shell theory and the Sanders-Koiter shell theory were two earlier typical nonlinear thin circular cylindrical shell theories. Bich and Nguyen [13] studied the nonlinear oscillations of functionally graded material (FGM) circular cylindrical shells based on the improved Donnell shell theory and found the beating oscillation phenomena. Jansen and Rolfes [14] analyzed the nonlinear free oscillations of laminated cylindrical shells based on the Donnell-type governing equations and found the internal resonances resulting in the interactions between the first-order mode and the second-order mode. Based on the Sanders-Koiter shell theory, Kurylov and Amabili [15] investigated the linear and nonlinear oscillations of circular cylindrical shells under both the

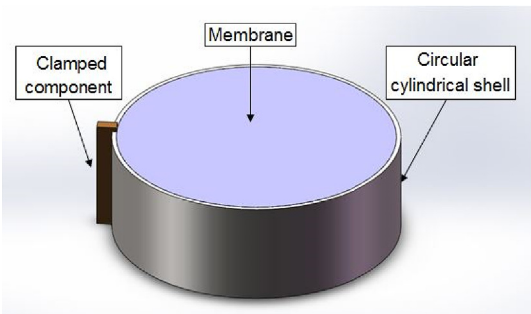

Fig. 2. The composite laminated circular cylindrical shell system is given.

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