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Continuous model and nonlinear dynamic responses of circular mesh antenna clamped at one side

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ABSTRACT

The continuous model and nonlinear dynamic responses of a circular mesh antenna subjected to the thermal excitation in the space environment are investigated for the first time. A continuum cantilever circular cylindrical short shell, which is clamped at one side of the shell along the axial direction, is proposed to take place of the circular mesh antenna composed of the repetitive beamlike lattice by the principle of equivalent effect. Based on the first-order shear deformation shell theory and von Karman nonlinear strain-displacement relationship, the nonlinear governing equations of motion are derived by using the Hamilton's principle. The Galerkin approach is used to transform the governing nonlinear partial differential equations into a set of nonlinear ordinary differential equations. The method of multiple scales is utilized to obtain the four-dimensional averaged equation when the 1:1 internal resonance is taken into account. The numerical results, which include the time histories, phase plots, and frequency spectrum, are obtained for the mesh antenna. The influences of the thermal excitation and the damping coefficient on the nonlinear dynamics are analyzed for the mesh antenna.

1. Introduction

The remarkable development of the astronautic science and technology leads to the increasing demand for advanced and large-scale space mesh antennas. The mesh antennas are served for different space missions, such as the earth observation, the land sensing and the deep space exploration. However, the mass and volume of these antennas are restricted by the capability of current launch vehicles. Therefore, the antennas are designed to be deployable, and desired to be as small as possible during transportation. The deployable mesh antenna has the advantage of high packing efficiency, low mass and large scale after deployment. In general, the mesh antenna is a periodic structure composed of repetitive beamlike lattice grids and has very large number of nodes. In order to investigate analytically the nonlinear dynamic responses of the circular mesh antenna, the cyclic periodic structure can be modeled as a continuum circular cylindrical shell supported at one side of the shell along the axial direction, as shown in Fig. 1. Compared to the finite-element method, the equivalent continuum circular cylindrical short shell model can be used to study theoretically and analytically the nonlinear vibrations, bifurcations and global dynamics of the circular mesh antenna, which can be comprehended more easily. The analytical results for the deflections of the nonlinear vibrations and the stress resultants of the continuum circular cylindrical shell for the circular mesh antenna can be obtained explicitly. Based on Ref. [1], it is found that after the circular mesh antennas are deployed in the space environment, there exist four basic vibration types which include the radial breath vibrations, the torsional, the bending and the rolling vibrations around support beam. This paper is further devoted to consider the radial breath nonlinear vibrations of the circular mesh antennas with 1:1 internal resonance and foundational parametric resonance.

The nonlinear partial differential governing equation of motion for the continuum circular cylindrical short shell of the circular mesh antenna can be transformed into a high-dimensional nonlinear system using the Galerkin approach. Due to the existence of the modal interactions in high-dimensional nonlinear systems, several types of internal resonant cases exist and can lead to different forms of the nonlinear vibrations. When a special internal resonant relationship between two linear natural frequencies exists, the large amplitude nonlinear dynamic responses may suddenly happen in the continuum circular cylindrical shell of the circular mesh antenna. The internal resonance is one of the main reasons result-

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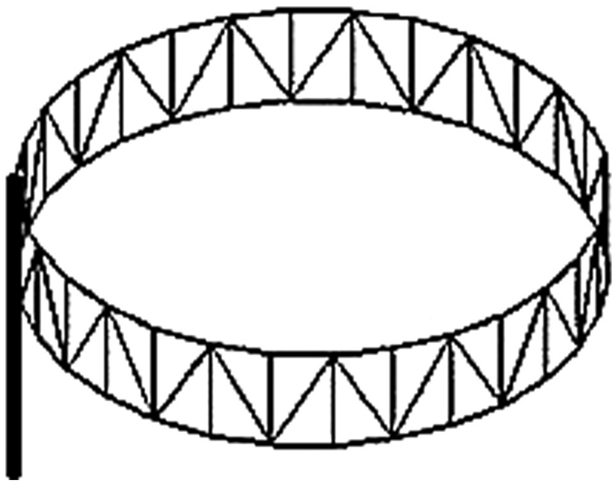

Fig. 1. The circular mesh antenna is displaced.

ing in the transfer of energy between two modes and causes the serious damage to the continuum circular cylindrical shell of the circular mesh antenna. For a continuum cantilever circular cylindrical short shell supported at one side of the shell along the axial direction, it is found that there exists the case of 1:1 internal resonance between the fourth-order mode and the fifth-order mode. Therefore, this paper focuses on investigating the nonlinear breath vibrations of the circular mesh antennas without considering the cable nets in the case of 1:1 internal resonance.

Over the past three decades, some literatures investigated the design and dynamic analysis problems of the mesh antenna. Mitsugi et al. [2] applied the flexible multi-body dynamics to analyze the deployment of a large space antenna composed of a reflective mesh, a cable network and a deployable truss structure. Tanaka [3] studied design optimization problems for large-scale contoured beam deployable satellite antennas based on the frequencies. Gan and Pellegrino [4] investigated a systematic problem of the kinematics of closed-loop structures, which have potential applications for next-generation deployable spacecraft structures. Na and Kim [5] used the Hamilton's principle and the Timoshenko beam theory to establish the governing equations of motion and analyze the deployment of a multi-link flexible structure. Li and Wang [6] used the absolute nodal coordinate formulation to study the flexible body dynamics of deployment antennas under different temperatures which were used to simulate the space environments. Bendiksen [7] considered the vibration localization phenomena of engineering structures including periodic or nearly periodic multi-span beams and multi-bay trusses, large space structures, space antennas, and almost periodic structures with circular symmetry. Alexandr et al. [8] investigated the Spacecraft dynamics due to a ring flexible antenna with a system of stabilization out-of-operation. Gasbarri et al. [9] investigated the uncertainties of the attitude control in the satellite with large flexible appendages. Morterolle et al. [10] presented a new approach to calculate a geodesic tension truss for the truss reflector that ensures both appropriate node positioning and uniform tension. Hu et al. [11] surveyed the advances on the nonlinear dynamics and control of large deployable space structures composed of trusses and meshes. Dai et al. [12] explored a new type of deployable antenna system composed of a double-ring deployable truss and cable nets. You et al. [13] established a nonlinear dynamic model of a rigid-flexible coupling the satellite antenna system composed of laminated shell antenna undergoing a large overall motion. Chu et al. [14] gave the modeling and analysis of a large deployable antenna structure. Liu et al. [15] investigated the dynamics modeling of spacecrafts with large deployable hoop-truss antenna and its coupling with spacecraft attitude motion.

The repetitive lattice-type structures have been used for a wild range of space applications due to their low mass and high stiffness. Several researchers have conducted the investigation works of the equivalent continuum model after considering the repetitive lattice grids. Noor et al. [16] developed continuum models for large repetitive beam-and-plate like lattices with arbitrary configurations subjected to dynamic loadings. Equivalent stiffnesses for laminated-composite flat plates and circular cylindrical shells stiffened by a grid of beam were presented by Chen et al. [17]. Moreau et al. [18] proposed a homogenization method to do the nonlinear static and modal analysis for the beam-like and plate-like lattice. Based on the energy equivalence, Burgardt et al. [19] gave a general procedure to determine the equivalent beam properties of beam-like lattice trusses. Tollenaere et al. [20] presented a method of continuous modeling for the quasi-repetitive lattice structures, which is called the discrete homogenization. Ziegler et al. [21] gave a general method to model the lattice block material as a continuum plate. Lombardo et al. [22] investigated the dynamic behaviors of the periodic lattice materials using an equivalent higher-order continuum model obtained by homogenization of the equations of motion. Qing et al. [23] studied the mechanical properties of the composites lattice structures with different width ratio of struts.

With the increased applications of circular cylindrical shells in aerospace engineering, the high temperature or temperature gradient is considered. A few investigations are conducted to study the nonlinear vibrations of circular cylindrical shells. Amabili [24] studied the nonlinear forced vibrations of a simply support circular cylindrical shell subjected to concentrated harmonic force. Jansen [25] studied the effect of static loading and imperfections on the nonlinear vibrations of cylindrical shells. Mallon et al. [26] experimentally and numerically investigated the dynamic stability of a harmonic base-excited thin orthotropic cylindrical shell carrying a top mass. Pellicano [27] studied the dynamic stability of circular cylindrical shells considering the combined effect of compressive static and periodic axial loads. Goncalves et al. [28] studied the global dynamics of isotropic shells due to a combination of static and harmonic axial loads. Hao et al. [29,30] investigated the nonlinear dynamics and bifurcations of functionally graded materials (FGM) shells subjected to large-amplitude harmonic radial loads. Zhang et al. [31] analyzed the nonlinear dynamics of a clamped–clamped FGM circular cylindrical shell under combined the external excitation and uniform temperature change. Kurylov et al. [32] experimentally and numerically analyzed large-amplitude nonlinear vibrations of a clamped-free circular cylindrical shell. Awrejcewicz et al. [33,34] investigated the chaotic dynamics of circular cylindrical shells and discussed the new scenarios of transition from the regular to chaotic orbits. Shen [35] analyzed the large amplitude nonlinear vibration behaviors of a shear deformable FGM cylindrical shell in thermal environments. Zhang et al. [36] studied the nonlinear dynamics of a shell-shaped workpiece during high speed milling subjected to a harmonic transverse cutting force.

In this paper, the nonlinear dynamic behaviors of a circular mesh antenna are investigated without considering the cable nets. The mesh antenna after the deployment is subjected to the thermal excitation in the space environment. The model of a cantilever equivalent circular cylindrical short shell, which is clamped at one side of the shell along the axial direction, is introduced to represent the circular continuum mesh antenna. It is thought that the mass of the equivalent circular cylindrical shell is equal to one of the mesh antenna. The effective stiffness coefficients of circular mesh antenna are derived by equating the displacements of the nodes of the rigid-jointed antenna structures to the displacements of the corners of the continuum shell element under the same