Nonlinear vibrations of sandwich shells with additive manufactured flexible honeycomb core interacting with supersonic gas flow

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Summary. The sandwich conical shell with three layers is considered. The middle layer of the structure consists of honeycomb core, which is manufactured by FDM additive technology from ULTEM 9085 material. Top and bottom faces are produced from the carbon fiber-reinforced composite. The self-structure vibrations are observed due to structure interactions with supersonic gas flow. The assumed mode method is used to obtain the system of nonlinear ordinary differential equations for the structure motions. The combination of the shooting technique and the continuation algorithm is used to study the structure periodic vibrations. The periodic and quasiperiodic self-sustained vibrations are discussed. The quasiperiodic vibrations are born due to the Naimark-Sacker bifurcation.

Introduction

Honeycomb sandwich structures are commonly used in aircrafts and launch vehicle structures because of their superior strength and stiffness. Honeycomb sandwich shell can be used to make rocket and missile head shell, engine tail nozzle, spacecraft fairing, solar cell shell and so on. Therefore, many efforts were made to study the mechanical properties of the honeycomb sandwich structures. Now the nonlinear vibrations of the honeycomb sandwich structures are treated. The nonlinear vibrations of smart viscoelastic composite doubly curved sandwich shell with flexible core and magnetorheological layer with different distribution patterns are treated in [1]. The nonlinear vibration analysis of composite sandwich doubly curved shell with a flexible core integrated with a piezoelectric layer is considered in [2]. The nonlinear dynamic behavior of the double curved shallow shells with negative Poisson's ratios in auxetic honeycombs on elastic foundations subjected blast is treated in [3]. A geometrically nonlinear forced vibration analysis of circular cylindrical sandwich shells with cellular core using higher-order shear deformation theory is presented in [4]. The paper [5] studies the nonlinear free and forced vibration of the sandwich cylindrical panel on Pasternak foundations in thermal environment under the action of blast load. The sandwich cylindrical panel consists of the auxetic honeycombs core and two carbon nanotube reinforced composite face sheets. The nonlinear dynamics of a double curvature sandwich shell with honeycomb are studied in [6].

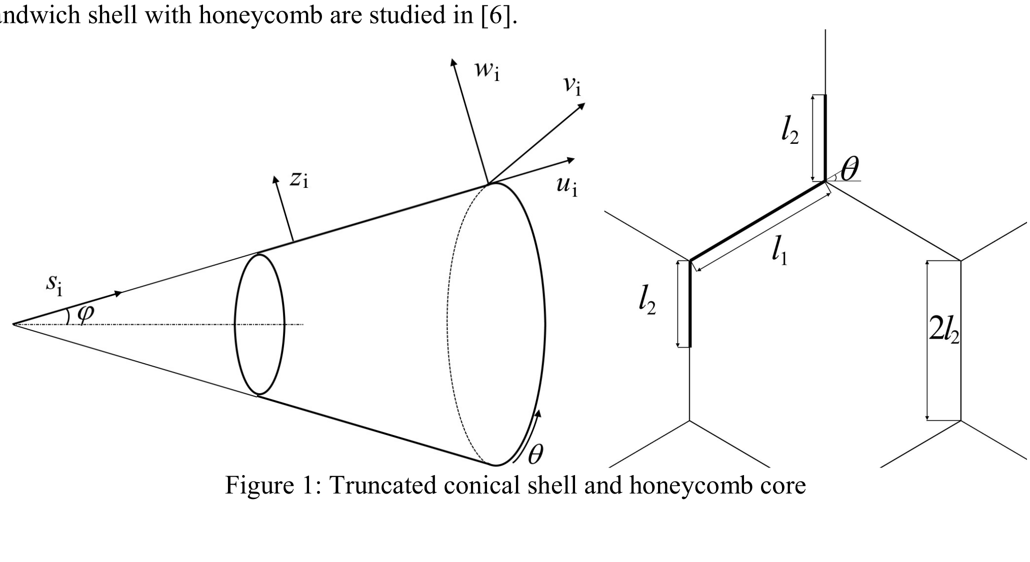

Figure 1: Truncated conical shell and honeycomb core

Problem formulation and main equations

The sandwich conical shell with three layers is shown on Fig.1. The middle layer of the structure consists of honeycomb core, which is manufactured by FDM additive technology (Fig.1) from ULTEM 9085 material. Top and bottom faces are produced from the carbon fiber-reinforced composite. The main geometrical parameters of the honeycomb cell (Fig.1) are the following: l_1, l_2, h_c, ψ, where h_c is thickness of the cells.

The dynamic instability and the self-sustained vibrations of the sandwich conical shell are treated. These nonlinear vibrations are take place due to interaction of the supersonic gas flow with the sandwich conical shell. The growth of vibrational amplitudes of thin-walled structures is observed due to the system dynamic instability. Then the geometrical nonlinearity contributes essentially to the nonlinear mathematical model of the sandwich structure. This geometrical nonlinearity limits of the vibrational amplitudes grow. This limitation results in the self-sustained vibrations. Therefore, the geometrical nonlinearity is taken into account. The faces composite material and the honeycomb materials satisfy the Hooke's law. The shell initial imperfections are not accounted here.

As the sandwich structure self-sustained vibrations are expanded by the eigenmodes, the linear vibrations of the sandwich structure are considered in this paper too.

The stress-strain state of the sandwich conical shell is studied in the curvilinear coordinate system. Three curvilinear coordinate systems, which are connected with the layers middle surfaces, are used. The curvilinear coordinate systems of the top, core and bottom layers are denoted as: $(s_t, \theta, z_t), (s_c, \theta, z_c), (s_b, \theta, z_b)$, where s_t, s_c, s_b are longitudinal coordinates directed along the generating line of the layer middle surface; θ is curvilinear coordinate (Fig.1); z_t, z_t, z_t are lateral coordinates of the layers.

Results of numerical analysis

The data of the self-sustained vibrations numerical simulations, which are observed due to interaction of supersonic gas flow with the sandwich conical shell is considered accounting geometrical nonlinear deformations. The nonlinear autonomous dynamical system of the structure vibrations has 21 degrees-of-freedom. This dynamical system is analyzed numerically by the algorithm, which combines the shooting technique and the continuation approach. Fig. 2 shows the result of the dynamical systems steady states. The dependences of the vibrational amplitudes $\max({}^{q_1}/_{h_c})$ on the pressure p_∞ is shown on the figure. The stable and unstable steady states are shown by solid lines and dotted lines, respectively.

The dynamical behavior of the structure, which are shown on Fig.2, are considered. The trivial equilibriums, which are described by the straight line (AB) (Fig.2), are observed at any value of p_∞. The Hopf bifurcation is taken place in the H point. The stable equilibriums (AH) are transformed into the unstable equilibriums (HB) and the stable self-sustained vibrations are born. These vibrations are described by the curve (HN_s). The Naimark-Sacker bifurcation is observed in the point N_s. Then the stable self-sustained vibrations are transformed into unstable ones and stable quasiperiodic vibrations are born. The amplitudes of such quasiperiodic vibrations are shown by the curve $(N_S D)$.

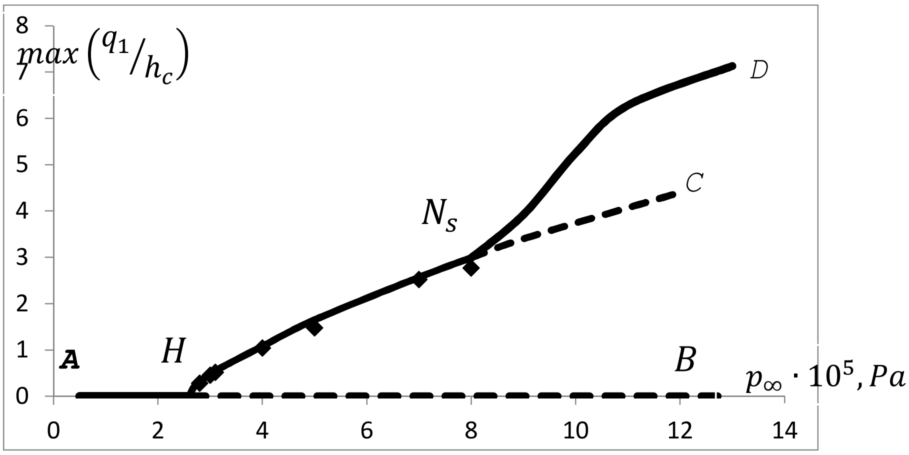

Figure 2: Bifurcation diagram of cantilever conical shell self-sustained vibrations at M=1.5

Acknowledgements

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