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Vibration suppression for truss core sandwich beam based on principle of nonlinear targeted energy transfer

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ABSTRACT

In this work, the dynamics of a truss core sandwich beam with NES (nonlinear energy sink) device are investigated. Based on the principle of nonlinear TET (targeted energy transfer), an NES device is placed in the interior of a sandwich beam to suppress vibration of the beam. The governing equation of motion for the sandwich beam with NES device attached is derived. The vibration responses of the system are analyzed under impulse and harmonic loads. Feasibility of the vibration suppression scheme is demonstrated by investigating the relation between the mass of the NES device and suppressing effect as well as the relative motion between the sandwich beam and the NES device. In addition, the influences of the NES parameters on the suppressing effect are studied. It is worth noting that the vibration suppression is enhanced with increasing the damping of NES when the system is excited by harmonic loads and with decreasing the damping when the system is excited by impulse loads. The influence of the nonlinear characteristic of spring on the vibration suppression depends on the selection of the other parameters of the NES.

1. Introduction

Three-dimensional periodic truss core sandwich structures are gradually becoming common in aeronautics and astronautics because of their high weight efficiency, high strength-to-weight ratio, designability, excellent characteristic of energy absorption and low thermal conductivity to name a few. However, the vibration of the truss core sandwich structures is a problem which can not be ignored. Particularly, aircraft and aerospace vehicles usually operate in severe conditions which may subject the sandwich structure to complex dynamic loads leading to large amplitude of vibration.

The vibrations of truss core sandwich structures have been highlighted by several researchers in recent years. Lou et al. [1] studied the free vibration of stainless steel pyramidal core sandwich beams. Xu and Qiu [2] investigated the free vibration of the composite truss core sandwich beams under consideration of uncertainties in geometric and material parameters. Lou et al. [3] analyzed the effects of local damage on dynamic properties of the composite truss core sandwich structures. Zhang et al. [4] studied the nonlinear frequency responses of a 3D-Kagome core sandwich plate by using the Reddy's third-order shear deformation theory. Li et al. [5] studied the local damage in composite truss core sandwich structures based on vibration characteristics. Chen et al. [6] investigated the influences of structural parameters on the hardening behavior of truss core sandwich plate by using a Zig-Zag theory. However, the investigations on the vibration control which especially aims to the sandwich structures has not been extensively investigated so far. Li and Lyu [7] investigated the active vibration control of the truss core sandwich beams employing piezoelectric materials. Song and Li [8] studied the nonlinear aeroelastic characteristics and the active flutter control of pyramidal core sandwich beams. Yang et al. [9] investigated the transverse vibrations and damping performances of pyramidal truss sandwich plates with viscoelastic layers embedded in the face sheets.

In view of load capacity of the truss core sandwich structure, a novel scheme of vibration suppression which based on the principle of nonlinear TET (targeted energy transfer) is proposed. TET, where energy of some form is transferred from a source to a receiver in a one-way irreversible fashion, governs a broad range of physical phenomena [10]. From the viewpoint of the vibration mitigation, the vibration energy is transferred from a primary structure to an NES (nonlinear energy sink) and then the energy cannot be transferred back to the primary structure. In the past

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decade, nonlinear TET has been increasingly used in the vibration control. Georgiades and Vakakis [11] analyzed the TET of a linear flexible beam with an NES under shock excitation. Kerschen et al. [12] studied the dynamics of passive energy transfer from a damped linear oscillator to an nonlinear end attachment. Gendelman [13] studied the TET in systems with external and self-excitation, the local and global bifurcations of the system are paid more attention. Ahmadabadi and Khadem [14] investigated the energy suppression of a cantilever beam with different configurations of NES under shock excitation. Lin and Oguamanam [15] analyzed the TET efficiency of a primary oscillator coupled to a nonlinear attachment. The TET efficiency is closely related to the 1:1 resonance capture and could be enhanced by strengthening the nonlinearity of NES. Zhang et al. [16] studied the vibration suppression for the axially moving beam by using the single NES and parallel NES, respectively. Kani et al. [17] presented the analysis on the TET between a nonlinear beam and an NES by using the complexification-averaging method.

Generally, the structure of the aircraft and aerospace vehicles is very compact. It is difficult to find free space to install one or more devices for vibration suppression. In order to reduce the vibration of truss core sandwich structure and overcome the problem of space requirement, the device can be placed inside the sandwich structure to absorb the vibration energy induced by external loads. For this purpose, the hollow part of the truss core sandwich structure can be used to accommodate the NES device. The governing equation of motion for a pyramidal core sandwich beam, with an NES device, is worked out using a Zig-Zag theory. The vibration response of the system under shock and harmonic loads are analyzed. Feasibility of the scheme is demonstrated and the influences of the NES parameters on the vibration suppressing effect are studied.

2. Governing equation

A simply supported pyramidal core sandwich beam with an NES device, attached inside the beam, is shown in Fig. 1. The sandwich beam consists of three layers including two thin face sheets on both sides and a pyramidal truss core in the middle of the sandwich beam. The material of the face sheets and truss core is aluminum. A Cartesian coordinate *oxz* is located in the middle surface of the sandwich beam, as shown in Fig. 1(a). The total thickness of the sandwich beam is represented by h. The thickness of each face sheet is represented by h_f and the height of the truss core is represented by h_c.

The truss core sandwich beam can be modeled as a beam which is composed of two solid layers and an equivalent continuum core layer. For the sandwich beam, the Allen's assumptions [18] can be written as,

(1). The thickness of the truss core sandwich beam remains constant during deformation;
(2). Only bending deformation is considered for both thin face sheets and only shear deformation is considered for the thick truss core;
(3). The deflections between each layer are continuous.

Based on the assumptions, the displacement field can be expressed in terms of the mid-plane displacements u_0, w_0 and rotations ϕ_x. The face sheets of the sandwich beam adopt the Kirchhoff hypothesis and the truss core adopts the first-order shear deformation theory [6,19].

$-\frac{h}{2} \leqslant z \leqslant -\frac{h_c}{2}$

$$u_t = u_0 - z\frac{\partial w_0}{\partial x} + \frac{h_c}{2}\left(\phi_x - \frac{\partial w_0}{\partial x}\right), \quad w_t = w_0,$$

$-\frac{h_c}{2} \leqslant z \leqslant \frac{h_c}{2}$

$$u_c = u_0 - z\phi_x, \; w_c = w_0,$$

$\frac{h_c}{2} \leqslant z \leqslant \frac{h}{2}$

$$u_b = u_0 - z\frac{\partial w_0}{\partial x} - \frac{h_c}{2}\left(\phi_x - \frac{\partial w_0}{\partial x}\right), \quad w_b = w_0,$$

where u and w represent respectively in-plane and transverse displacements. The subscripts t, c and b represent the top face sheet, the truss core and the bottom face sheet respectively.

Using the Hamilton's principle, the governing equations of motion for the truss core sandwich beam with NES attached are obtained.

$$\frac{h_c^2}{2}A\frac{\partial^2\phi_x}{\partial x^2} - \frac{h_c^2}{2}A\frac{\partial^3 w_0}{\partial x^3} - h_c B\frac{\partial^3 w_0}{\partial x^3} - C\phi_x + C\frac{\partial w_0}{\partial x} = 0 \tag{1a}$$

$$\begin{aligned}&\left(\frac{h_c^2}{2}A + Bh_c\right)\frac{\partial^3\phi_x}{\partial x^3} + \left(-\frac{h_c^2}{2}A - 2Bh_c - 2D\right)\frac{\partial^4 w_0}{\partial x^4} - C\frac{\partial\phi_x}{\partial x}\\ &\quad + C\frac{\partial^2 w_0}{\partial x^2} + F - \mu_1\dot{w}_0\\ &\quad + \left\{K[v_0 - u_0]^\alpha + \mu_2[\dot{v}_0 - \dot{u}_0]\right\}\delta(x-a) = I\ddot{w}_0\end{aligned} \tag{1b}$$

$$m\ddot{v}_0 + K[v_0 - u_0]^\alpha + \mu_2[\dot{v}_0 - \dot{u}_0] = 0 \tag{1c}$$

where m is the mass of the NES, and K is the equivalent stiffness of the parallel springs in NES device. A, B, C and D are, respectively, the extensional, bending-extensional coupling, shear and bending stiffnesses of the sandwich beam. μ_1 and μ_2 are the dampings of sandwich beam and NES, respectively. F represents loads which is imposed on the beam. $u_0 = w_0(a,\ t)$, where, a represents the loca-

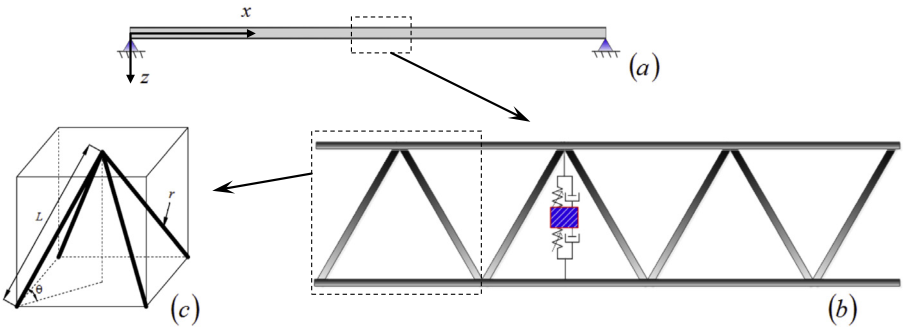

Fig. 1. A truss core sandwich beam with NES attached.