Parameter Characterisation of the Bouc/Wen Mechanical Hysteresis Model for Sandwich Composite Materials using Real Coded Genetic Algorithms

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(Received 28 September 2004; accepted 24 February 2005)

One major advantage of composite materials for structural and machinery applications is their relatively high energy dissipation characteristics. Accordingly for advanced design applications, it is important to have a thorough understanding of the material damping behaviours. In general, material damping tends to be a complex nonlinear function of vibration amplitude, frequency, loading, and material formulation. One approach for identifying damping characteristics uses mechanical hysteresis curves. It is well recognised that the area enclosed by such curves is proportional to the energy dissipation per cycle of oscillation. However, the specific shape of the curve also has important implications for characterising the specific functional form of the damping. Therefore, it is important to develop methods for accurately accounting for such effects. The current work explores the application of Real Coded Genetic Algorithms (RCGA) for curve-fitting a nonlinear mathematical model (the Bouc/Wen Hysteresis Model) to synthetic (computer-generated) and experimentally obtained hysteresis loops for a sandwich composite material. The model depends on seven parameters, for which patterns and tendencies are searched as functions of the type of material. The solutions of the model enable us to determine also the contributions of the nonlinearities to the energy dissipation.

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Nomenclature

EI – flexural rigidity (Nm^2)
w – transverse displacement (m)
x – longitudinal position (m)
t – time (s)
ρA – mass per unit length (kg/m)
f – forcing function per unit length (N/m)
F – excitation force amplitude per unit length (N/m)
ω – excitation angular frequency (rad/s)
L – length of the beam (m)
M_{tot} – total mass of the beam (kg)
M_{eq} – equivalent mass of the beam (kg)

1. INTRODUCTION

Interest in the development of improved composite materials has greatly increased in recent years due to their high energy dissipation characteristics and high stiffness-to-weight ratios. They are used in a variety of highly demanding structural applications, including aircraft, submarines, and military vehicles. There are numerous types of composites currently available, including carbon fibre, metal matrix, and ceramic matrix composites. Of particular interest in the current work is a specific variation of composite construction called "sandwich composites" or "sandwich panels."

The term "sandwich panel" refers to a structure consisting of two thin faces bonded to a thick lightweight core. Photographs of some typical sandwich composite structures, with a honeycomb core, are shown on Fig. 1. The faces are typically of aluminum or some composite laminate, and the core could be a lightweight foam or a honeycomb structure.

1.1. Mathematical Model

There are a number of mathematical models for hysteresis (orbit plot of displacement vs. applied force) currently available in reference[1], such as hysterons, Bouc/Wen[2-3], Chua-Stromsmoe, and Preisach methods. For the purpose of characterising the dynamics of mechanical structures, the Bouc/Wen nonlinear hysteresis model appears to be a good choice because of its form (mass-spring-viscous damper equivalent differential equation of motion) and its versatility. Hence, this model has been selected in the current work to characterise the dynamics (particularly the damping behaviours) of sandwich composite structures. Numerous researchers have successfully used this model. For example, Ni[4] and Constantinou[5] used it for the study of nonlinear hysteretic isolators, Smyth[6] for an adaptive application, and Heine[7] for an optimisation approach to degrading hysteretic joints with slack behaviour.

The Bouc/Wen hysteresis model is a system of nonlinear differential equations defined by Eq. (1):

$$\ddot{x} + 2\xi\omega_n\dot{x} + \alpha\omega_n^2 x + (1-\alpha)\omega_n^2 z = f(t);$$

$$\dot{z} = -\gamma|\dot{x}||z|^{(n-1)}z - \beta\dot{x}|z|^n + a\dot{x}, \qquad (1)$$

where the parameters of the system are: α is the rigidity ratio $(0 \le \alpha \le 1)$, ξ is the linear elastic viscous damping ratio $(0 \le \xi \le 1)$, ω_n is the pseudo-natural frequency of the system (rad/s), a is the parameter controlling hysteresis amplitude, and β, γ, n are parameters controlling hysteresis shape $(n \ge 1)$.