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Non linear vibrations of imperfect fluid-filled viscoelastic cylindrical shells

Zenon J. G. N. del Prado[a]*, Marco Amabili[b] and Paulo B. Gonçalves[c]

[a] *Escola de Engenharia Civil, Federal University of Goias, Av. Universitária, s/n, Setor Universitário, 74605-200, Goiânia, GO, Brazil*
[b]*Department of Mechanical Engineering, McGill University, 817 Sherbrooke Street West, H3A 0C3, Montreal, Canada*
[c]*Catholic University of Rio de Janeiro, Department of Civil Engineering, Rua Marquês de São Vicente, 225, Gávea, 22453-900, Rio de Janeiro, RJ, Brazil*

Abstract

In this work the effect of geometric imperfections on the non-linear dynamics of simply supported viscoelastic fluid-filled circular cylindrical shells subjected to lateral harmonic load is studied. Donnell's non-linear shallow shell theory is used to model the shell, assumed to be made of a Kelvin-Voigt material type, and a modal solution with eight degrees of freedom is used to describe the lateral displacements. The Galerkin method is applied to derive a set of coupled non-linear ordinary differential equations of motion. The influence of shell geometry, flow velocity and dissipation parameter are studied and special attention is given to resonance curves and bifurcation diagrams. Obtained results show that geometric imperfections together with the viscoelastic dissipation parameter and internal fluid have significant influence on the nonlinear dynamic behavior of the shells as displayed in resonance curves.

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1. Introduction

Circular cylindrical shells have been extensively used in modern industrial applications and have made their analysis an important research area in applied mechanics and biomechanics. Viscoelastic characteristics can be found in biological materials, elastomer and metals under high temperature. In spite of a large number of studies on cylindrical shell dynamics, just a small number of these works is related to the analysis of viscoelastic shells and a

* Corresponding author. Tel.: +55 62 3251-6084; fax: +0-000-000-0000 .
E-mail address: zenon.prado@gmail.com

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detailed review of studies on shells can be found in the literature [1]. Several mechanical models are used to describe viscoelastic material responses such as Maxwell, Kelvin-Voigt, Boltzman and Standard linear solid models. Even its limitations, the Kelvin-Voigt model can describe the creep phenomenon and has been used to describe vibrations of viscoelastic materials

The nonlinear dynamic behavior of viscoelastic cylindrical shells subjected to axial loads using the Von Kármán-Donnell non-linear shell theory was studied by [2,3]. In a series of papers [4,5,6,7,8] the vibrations and dynamic stability of viscoelastic cylindrical shells and cylindrical panels with and without concentrated masses using the Kirchhoff-Love hypothesis and Timoshenko theories by taking into account shear deformation and rotary inertia were studied. The effect of lateral pressures on compressible non-linearly viscoelastic cylindrical and spherical shells under time-dependent pressures was studied by [9] and the thermal post-buckled characteristics of cylindrical composite shells with viscoelastic layers, considering transversal shear deformation and variable in-plane displacements through the thickness of the shell was studied by [10]. The radial motions of cylindrical and spherical shells under pulsating pressures considering non-linear viscoelasticity was considered by [11] and [12] studied the vibration of cylindrical shells with thin or thick core layer based using a new higher-order expansion of transverse and in-plane displacement fields in the thickness direction of the core layer. Recently, [13] studied experimentally and numerically the nonlinear vibrations of viscoelastic plates using the Kelvin-Voigt model. It was observed that experimental results fit very well with numerical results even for large amplitude oscillations, showing that the viscolestaic model, even been a simply one, can display good accuracy.

In the present work, the influence of material properties and geometric imperfections on the non-linear vibrations of an imperfect simply supported viscoelastic circular cylindrical shell with internal fluid and subjected to lateral harmonic load is studied. Donnell's non-linear shallow shell theory is used to model the shell, which is assumed to be made of a Kelvin-Voigt material type, and a modal solution with eight degrees of freedom which takes into account the essential modal couplings and interactions is used to describe the lateral displacements of the shell. The Galerkin method is applied to derive a set of coupled non-linear ordinary differential equations of motion that are, in turn, solved by the Runge-Kutta method.

As a first attempt and using the tools of nonlinear dynamics, a deep parametric study will be conducted to try to investigate the non-linear large-amplitude vibrations with emphasis on the influence of the viscoelastic coefficient and external load on resonance curves. In this study and since it is the most simple, the Kelvin-Voigt constitutive model was adopted and, to the authors' best knowledge, no previous studies have been done focusing to understand the nonlinear behavior of viscoelastic imperfect cylindrical shells. Of course, all these results will give a detailed description of the problem and will be a basis for future adoption of more complex constitutive viscoelastic models considering stress relaxation.

2. Mathematical Formulation

Consider an imperfect thin-walled fluid-filled simply supported circular cylindrical shell of radius R, length L and thickness h. The axial, circumferential and radial coordinates are denoted by x, $y = R\theta$ and z, respectively, and the corresponding displacements of the shell middle surface are denoted by u, v and w, as shown in Fig. 1. The shell is assumed to be made of a Kelvin-Voigt viscoelastic material with initial Young's modulus E, Poisson ratio ν, and density ρ.

The shell is subjected to the following harmonic lateral pressure:

$$f = F_L h^2 \rho \omega_o^2 \sin(m\pi x/L)\cos(n\theta)\cos(\omega_L t) \tag{1}$$

where F_L is the non-dimensional coefficient of the amplitude of the load, ω_0 is the natural frequency of the shell, m ,the number of axial half-waves, n , the circumferential wave number, ω_L , the frequency of the load and t the time.

In this analysis, the viscoelastic behavior of the material is modeled in the base of the Kelvin-Voigt viscoelastic theory. Considering the plane stress problem and the Kelvin-Voigt constitutive model of a viscoelastic material, the stress-strain relations can be written as [14]: