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NONLINEAR VIBRATIONS OF THERMOMECHANICALLY COUPLED LAMINATED PLATES IN A UNIFIED REDUCED ORDER MODELING FRAMEWORK

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A unified formulation of the 2D thermomechanical problem of laminated plates undergoing finite amplitude vibrations is presented. It integrates mechanical and thermal aspects, and embeds a multitude of possible continuous models resulting from different assumptions about the plate mechanical and thermal configurations. A comprehensive and unified classification and comparison of various modeling assumptions concerned with (i) geometric nonlinearities, (ii) shear deformability and (iii) thermal involvement is performed.

The resulting models are not equally advantageous. As regards geometric nonlinearities, general models accounting for all of them [1] involve significant computational difficulties when aiming to obtain minimum order discretized models for the analysis of nonlinear vibrations through the procedure generally used for von Karman models. On the other hand, von Karman strains - although involving some quadratic and cubic terms - do not account for the change of structural configuration within the curvature-displacement relationship, because of considering only linear terms in the curvature expressions. Yet, the neglected geometric nonlinearities may entail non-negligible effects in the nonlinear analysis of composite plates [2]. Therefore, in addition to the general and von Karman types of continuous models, intermediate models [3] also accounting for nonlinear terms in the curvature expressions (unlike von Karman) are considered. They retain the great advantage of all von Karman models as regards performing minimal reductions.

Within the context of a Galerkin discretization, the minimum reduced order model of a nonlinear composite plate with thermoelastic coupling (for the continuous models that allow it) turns out to be constituted by a system of three coupled nonlinear ordinary differential equations of variable order, depending on the multiphysics character of the problem. They can be further reduced to two ODEs or even to a single ODE if decoupling the elastic aspects from the thermal one. Overall, the nonlinear dynamics of the underlying continuous models of different richness and accuracy can be analyzed.

Focusing on thermoelastic plates with solely von Karman nonlinearities, lower order discrete models are obtained from the complete one with three fully coupled ODEs [4]. They exhibit variable nonlinear features associated with the presence/absence of mechanical and/or thermal excitations and with consideration of coupling terms. Neglecting membrane and/or bending thermal dynamics ends up with the occurrence of an actually two-way or a solely single-way coupling. Based on the possible importance of thermomechanical phenomena in free and forced nonlinear vibrations, ensuing from comparative numerical investigations, the suitability and effectiveness of simplified models in reliably describing thermal effects under variable system and excitation conditions is comparatively discussed.

Within the multitude of parameters governing the reduced order models, some of them – accounting for thermoelastic stiffnesses, coefficients of thermal expansion, thermal capacity, and reference temperature –

are seen to induce a significant thermoelastic damping causing decay of the vibration amplitude [4, 5]. Possibly chaotic responses of (partially) uncoupled models are seen to be regularized by the full coupling effects of the complete model. A systematic analysis of the influence of thermomechanical coupling on the nonlinear vibrations of laminated plates is presently going on.

In view of application purposes, the comparative analysis of the reduced models may throw useful light on the possibility to exploit thermal effects to favorably affect the system response via an appropriate control of some parameter.

[1] Pai, P.F., Nayfeh, A.H.: A nonlinear composite plate theory. Nonlinear Dynamics 2, 445–477 (1991).

[2] Rega, G., Saetta, E.: Nonlinear curvature-based model and resonant finite-amplitude vibrations of symmetric cross-ply laminates. Journal of Sound and Vibration 331, 2836–2855 (2012).

[3] Rega, G., Saetta, E.: Shear deformable composite plates with nonlinear curvatures: modeling and nonlinear vibrations of symmetric laminates. Archive of Applied Mechanics 82, 1627-1652 (2012).

[4] Saetta, E., Rega, G., Unified 2D continuous and reduced order modeling of thermomechanically coupled laminated plates for nonlinear vibrations. Meccanica (2014), doi: 10.1007/s11012-014-9929-6.

[5] Yeh Y.-L.: The effect of thermo-mechanical coupling for a simply supported orthotropic rectangular plate on non-linear dynamics. Thin-Walled Structures 43, 1277–1295 (2005).