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Nonlinear Vibroacoustic Analysis of Functionally Graded Plates in the Thermal Ambiance at Oblique Incidence

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Abstract. In this investigation, the analysis of the nonlinear vibroacoustic and sound transmission loss behaviors of plates made of functionally graded material is presented. It is assumed that the properties of the functionally graded plates are in the form of the simple power law scheme and continuous along the thickness, under thermal load and incident oblique plane sound wave as well as the first-order shear deformation theory. For this purpose, first, using Hamilton's principle, the nonlinear partial differential equations of motion are derived by the displacement field function approach and by considering the nonlinear von Kármán strain-displacement relations. To solve the equations, using the Galerkin method, the nonlinear partial differential equations of motion lead to Duffing equation. Then, using the homotopy analysis method, the equation of the transverse movement of the plate is solved semi-analytically to obtain the nonlinear frequencies. Finally, the nonlinear vibration and acoustic response of functionally graded plates are studied by considering the variation of the important parameters such as aspect ratio, dimensionless amplitude, volume fraction power of functionally graded material, external acoustic pressure, incidence and azimuthal angles, temperature changes, phase portrait, sound transmission loss, velocity and average mean square velocity of drive point and sound power level of the functionally graded plate. Results show increasing the incidence angle leads increase in hardening effects and sound transmission loss, but growing the azimuthal angle does not have much effect on the frequency-response and sound transmission loss in the absence of the external mean flow. Also, increasing temperature changes lead to decrease in hardening effects and sound transmission loss.

AMS subject classifications: 74E30, 74F05, 74G10, 74H45, 74K20, 70K50, 76Q05

Key words: Nonlinear vibroacoustic, functionally graded plate, first-order shear deformation theory, displacement field function approach, homotopy analysis method.

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1 Introduction

Noise transmission is a crucial subject in the design of many structures, such as walls and floors of buildings, ship hulls, and side walls, and airplane and train cabins; Because noise, in addition to harassing the crew and passengers, may lead to fatigue of the structure and even catastrophic failures in the system. As a result, over the years, various analytical models have been presented and developed to predict the characteristics of the sound transmission. These models may be further classified as high-frequency or low-frequency noise models. In high-frequency noise, the panel dimensions are vast compared to relatively short sound wavelengths; therefore, the panel can be modeled analytically using the infinite panel theory. In low-frequency noise, panel dimensions are comparable to long-wavelength sound, and boundary effects are essential. In this approach, the panel is usually modeled as a rectangular simply supported plate in an infinite baffle. When a panel with infinite length is acoustically excited, the frequency at which the speed of sound in the air equals the speed of the free bending wave is named the critical frequency [1]. Critical frequency is especially significant when dealing with sound radiation from structures. The characteristics of sound radiation depend on whether the incitement frequency is higher or lower than the critical frequency. Similarly, the sound radiation efficiency of structure is very high near the critical frequency. The behavior of plates with limited length is shown in the same way. When a structure is acoustically excited, the frequency at which the speed of the free bending wave equals the speed of the forced bending wave is called the coincidence frequency [1]. Sound transmission close to the coincidence frequency is very high. Sound transmission characteristics hinge on whether the incitement frequency is higher or lower than the coincidence frequency. The vibrational response of a plate to the sound field around its critical frequency is the greatest. So, to find the structure response to sound incitement, it is necessary to know its critical frequency precisely. If it is necessary to reduce the response, the critical frequency information of the structure can be applied in its plan. For instance, the structure can be planned so that the critical frequency is outside the kind of frequencies in which the acoustic incitement is greater. Therefore, knowing the information about the critical and coincidence frequencies of structure is necessary to learning its structural-acoustic relations. It should be intentioned that these two parameters are interdependent. The critical and coincidence frequencies of the plates have been debated in particular in references [2–4].

Functionally graded materials (FGM) are composite materials whose mechanical or thermal specifications vary functionally and continuously from one level to another. The use of FGM in recent decades is a significant increase. Since these materials have high thermal resistance, they have many engineering usages in productions, for example, defense and aerospace productions. Also, these materials are applied in the structure of tools, for example, nuclear reactors, turbine blades, pressure vessels, heat exchangers, biomedical materials such as dental implants, and chemical productions. Panels are one of the common structures made of FGM that have many uses in engineering con-