Advances in Applied Mathematics and Mechanics
Adv. Appl. Math. Mech., Vol. **13**, No. 4, pp. 914-941

DOI: 10.4208/aamm.OA-2019-0333
August 2021

# An Analytical Solution for Nonlinear Vibration Analysis of Functionally Graded Rectangular Plate in Contact with Fluid

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Received 15 November 2019; Accepted (in revised version) 6 May 2020

**Abstract.** In this paper, the nonlinear vibrations analysis of functionally graded (FG) rectangular plate in contact with fluid are investigated analytically using first order shear deformation theory (FSDT) for the first time. The pressure exerted on the free surface of the plate by the fluid is calculated using the velocity potential function and the Bernoulli equation. With the aid of von Karman nonlinearity strain-displacement relations and Galerkin procedure the partial differential equations of motion are developed. The nonlinear equation of motion is then solved by modified Lindstedt-Poincare method (MLPM). The effects of some system parameters such as vibration amplitude, fluid density, fluid depth ratio, volume fraction index and aspect ratio on the nonlinear natural frequency of the plate are discussed in detail.

**AMS subject classifications**: 74B99, 74E30, 74F10, 74G10, 74H45

**Key words**: Nonlinear vibration, functionally graded materials, fluid pressure, first order shear deformation theory, modified Lindstedt-Poincare method.

## 1 Introduction

Functionally graded materials (FGM) are a type of composite materials whose mechanical and thermal properties change from one surface to another according to a continuous function. The use of FGMs has increased significantly in recent decades. Due to its high thermal resistance and other properties, FGMs have many engineering applications in various industries such as defence industries and aerospace industries. FGMs are commonly used in the construction of equipment such as pressure vessels, turbine blades, heat exchangers, biomaterials like dental implants and etc.

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Chaabaneet et al. [1] presented an analytical study for bending and free vibration behaviour of FG beams resting on elastic foundation. Medaniet et al. [2] studied the static and dynamic behaviour of FG-carbon nanotube (FG-CNT) reinforced porous sandwich plate. Boulefrakhet et al. [3] analysed the effect of parameters of visco-Pasternak foundation on the bending and vibration properties of a thick FG plate. Berghoutiet et al. [4] investigated the vibration analysis of nonlocal porous nanobeams made of FGMs. Tlidjiet et al. [5] investigated vibration analysis of different material distributions of functionally graded micro beam. Bouradaet et al. [6] studied the dynamic analysis of porous FG beam using a sinusoidal shear deformation theory. Karamiet et al. [7] investigated resonance behavior of FG polymer composite nameplates reinforced with grapheme nano platelets. Meksiet et al. [8] presented an analytical solution for bending, buckling and vibration responses of FGM sandwich plates.

Plates are one of the most common FG structures which have many applications in the practical engineering. Therefore, due to their high importance, many studies have been reported on the dynamics of FG plates. Some researchers worked on the vibrations of FG plates based on classical plate theory (CPT). Zhang and Zhou [9] investigated free vibration, deflection and buckling analysis of the FG plates using the CPT based on physical neutral surface. Abrate [10] calculated natural frequencies of FG clamped and simply supported rectangular thin plates based on the CPT. Sahlaet et al. [11] analysed free vibration behaviour of angle-ply laminated composite and soft core sandwich plates.

Since rotatory inertia and shear deformation are neglected in the CPT, results given by CPT are admissible only for thin plates. As a result, some researchers used first order shear deformation theory (FSDT) to take into account the effects of rotary inertia and shear deformation to analysis of thick plates [12–18]. Hosseini-Hashemiet et al. [19] presented analytical method for analysis of free vibrations of FG rectangular plate on an elastic foundation using FSDT. By using element free kp-Ritz method, Zhaoet et al. [20] carried out the free vibrations of FG rectangular plate based on FSDT. They considered four types of FGM in their investigation. Yang and Shen [21] analyzed the free and forced vibrations of initially stressed FG plate in thermal environment with different boundary conditions on the basis of the FSDT. Guptaet et al. [22] obtained linear frequencies of rectangular plate with different boundary constraint by using FSDT. Addouet et al. [23] investigated the dynamics response of FG plates with porosity resting on different foundation using quasi three dimensional higher order shear deformation theory (HSDT). Boutalebet et al. [24] studied dynamic analysis of nanosize FG rectangular plates based on simple nonlocal quasi three dimensional HSDT. Khiloun et al. [25] investigated the bending and vibration analysis of thick advanced composite plates using a four-variable quasi three dimensional HSDT. Boukhlifet et al. [26] presented a simple quasi three dimensional HSDT for the dynamics analysis of FG thick plate on elastic foundation. Draouiet et al. [27] analysed the static and dynamic behaviour of nanotubes-reinforced sandwich plates using FSDT. Zaouiet et al. [28] presented new two and quasi three dimensional shear deformation theories for free vibration analysis of FG plates on elastic foundations. Based on a simple HSDT, Hellalet et al. [29] investigated dynamic and stability analysis of