Dynamics of Deformable Fractal Surface in Contact with Harmonically Excited Rigid Flat

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ABSTRACT

Dynamics of contact between a deformable fractal rough surface and a rigid flat is studied under harmonic excitation to the flat surface. Fractal surface is generated from the modified Weierstrass-Mandelbrot function and is imported to ANSYS to construct the finite element model of the same. A parameter called ‘nonlinearity exponent’, is obtained from the force-displacement relationship of the rough surface and is used to find out the dynamic properties of the contacting interface using single spring-mass-damper model. The effect of variation in surface roughness and material properties on the system response is analyzed. The system exhibits superharmonic responses for different values of the nonlinearity exponent. The phase plot and time-displacement plots for the system are also furnished.

KEYWORDS

Contact Vibration, Fractal Surface, Harmonic Excitation, Material Properties, Rigid Flat

1. INTRODUCTION

Hertzian theory has so far been employed extensively for modeling dynamic contact interactions between rough surfaces. First significant theoretical work on contact dynamics was by Nayak (1972), who developed some of the theoretical groundwork necessary for detailed physical explanations of experimentally observed phenomena in vibratory point contact by modelling a single-degree-of-freedom dynamic system and obtained analytical solutions by using a single term harmonic balancing method (HBM). Hess and Soom (1991a, 1991b) studied nonlinear vibrations at a Hertzian contact excited by the dynamic component of an externally applied normal load by using the method of multiple scales (MMS) (Nayfeh and Mook, 1979). The authors obtained solutions for both the average and instantaneous contact deflections and quantified the amount of friction reduction due to contact vibration. Perret-Liaudet (1997, 1998) investigated a sphere-plane (Hertzian) contact problem for sub-
harmonic and super-harmonic resonance of order two using MMS and expanding the nonlinearity by third order Taylor series. The condition for contact loss was taken into consideration for the first time in this work. Sabot et al. (1998) studied the non-linear vibrations of a sphere–plane contact excited by a normal load equal to the sum of a static load and a harmonic load and predicted the contact natural frequency, frequency contents and softening behavior using numerical and analytical methods. Perret-Liaudet and Sabot (1999) analyzed the sphere-plane model of Hertzian contact by numerical methods and confirmed the significance of clearance at the contact on super-harmonic and sub-harmonic resonances, which lead to vibro-impact responses. Rigaud and Perret-Liaudet (2003) and Perret-Liaudet and Rigaud (2003) investigated dynamic behaviour of a preloaded double sphere–plane Hertzian contact under sinusoidal excitation and random normal excitation and solution was obtained using the shooting method in conjunction with parametric continuation technique. The authors also analyzed the dynamic response of an impacting Hertzian contact subjected to an order-2 subharmonic excitation and an order-2 superharmonic excitation [Perret-Liaudet and Rigaud, (2006, 2007)]. Ma et al. (2007) studied the sphere-plane contact model with possible contact loss experimentally and analytically using a multi-term harmonic balancing method. Tian and Xie (2008) analyzed the dynamic contact stiffness at the interface between a vibrating rigid sphere and a semi-infinite transversely isotropic viscoelastic solid with a harmonic force superimposed onto a static compressive force. Xiao et al. (2011) used exact method, MMS and HBM to determine the natural frequency of a mass interacting with a nonlinear contact stiffness. Zili et al. (2013) employed fractal contact model in conjunction with thin layer elements to capture the effects of lightly clamped joint interfaces on the dynamics of assembled structures taking the effects of surface topography, preload, and material properties into account. Xiao et al. (2015) modelled an elastic fractal surface contacting with a rigid flat surface. The authors analyzed its force-displacement relation and studied the free and forced vibration responses of the system.

From the literature survey it has been found that dynamic fractal surface contact with rigid flat surface is contained to an elastic domain. However, realistic materials are not infinitely elastic and exhibit definite yield point. Post elastic dynamic behaviour of rough surface in contact with rigid flat remains largely unexplored. Hence, in the present paper the effect of variation of material properties such as tangent modulus (assuming bilinear model) and yield strength values of the contacting rough surfaces on forced vibration responses of the system is analyzed. Forced response of the system corresponding to variation of fractal parameters is also studied. A three-dimensional rough fractal surface is generated using a modified two-variable Weierstrass-Mandelbrot function [Yan and Komvopoulos (1998)] and the force-deflection relationship of the rough surface contacting with a rigid flat surface is determined through finite element analysis using commercial FEA package ANSYS. External harmonic excitation in the form of displacement is imparted on the rigid flat surface. For the present system, the equation of motion is represented by a forced Helmholtz–Duffing equation whose characteristics are dependent on the power value of the force-displacement relationship. Solution of the above mentioned equation leads to frequency response curves of the system. Superharmonic responses are obtained for the system and it is analyzed for the variation of the nonlinearity exponent value.

2. FRACTAL SURFACE MODELING

3D fractal surface topography [Ling (1990)] can be utilized to realistically model rough surfaces. In the present paper the fractal surface is generated following modified two-variable Weierstrass-Mandelbrot function [Yan and Komvopoulos (1998)] expressed mathematically as follows:
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