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Transient response characteristics of a bolted flange connection structure with shear pin/cone

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ABSTRACT

Transient response characteristics of a bolted flange connection structure with shear pin/cone under different types of load are studied by a simplified dynamical model with material nonlinearity. It is found that different ratios of the longitudinal vibration frequency to the bending vibration frequency lead to superharmonic response or sub-harmonic response. The computational results indicate that the classical linear model is inadequate for studying the transient response of the bolted flange connection structure when the ratio of the longitudinal vibration frequency to the bending vibration frequency is around 2:1. Moreover, to reveal the effect of inclination angle of shear pin, a contour map of the transient response of the connection structure is illustrated over an angle range from 0° to 40°. It is found that the inclined shear pin redirects a part of transversal loads to longitudinal force.

Contents

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1. Introduction

Bolted flange connection structures are widely used in many industrial fields, such as in civil engineering, mechanical engineering, aeronautics and astronautics engineering, nuclear industry and national defense equipments. Many of these structures carry dynamical loads or impact loads in complex working environments. Therefore, it is very important to study the transient response of these structures under dynamic loading in structural design [1–4].

Many analytical works have been done for establishing dynamic models of the bolted flange connection structures, and can be roughly categorized as two different ways [5–9]. The first way is using the classical models such as Iwan or Dahl model [10–13]. Mignolet et al. [14] developed a stochastic Iwan-type model for the characterization of a particular class of bolted joints, and verified this model by available experimental data with broad scatter on the stiffness and dissipation behavior. Ahmadian et al. [15] developed a reliable procedure for identifying the parameters in the Iwan model by relating the density function to the joint interface dissipated energy. Li et al. [16,17] developed a six-parameter Iwan model to simulate joint experiments with different preload techniques. They further used this model to describe the phenomena of residual stiffness and power-law relationship. Piatkowski [18] presented a method for determining the parameters used in LuGre and Dahl dynamic friction models. Wojtyra [19] found a high parametric sensitivity of Dahl model when a rigid body approach was used to analyse the static friction in closed loop mechanisms.

Another way is developing new models for bolted flange connection structures. EI-Zahry [20] derived a realistic linear mathematical model from simple spring-mass system analysis. Using this model, he studied the response of a bolted joint subjected to a harmonic excitation. Duffey [21] developed a simple spring-mass model for closure bolting systems by ignoring viscous damping of the bolt in response analysis of single-degree-of-freedom (SDOF) mass-spring system under impact load with exponential attenuation. Based on this model, he proposed the corresponding relationship between bolt prestress and stress peak value under special conditions. Swansona et al. [22] established a three-dimensional solid model of bolt connection with contact and non-linear material characteristics, and studied the influence of bolt position and flange thickness on the stress distribution of flange. Wang et al. [23] derived a practical design model for prediction of yield and bending of the joints, to study the bending characteristics of connections of wing panel under bending moment. Scarselli et al. [24] proposed a simplified physical model for analyzing the hysteretic response of bolt connection under cyclic loading. Luan et al. [25] established a flange bolt connection model with different stiffness values for tension and compression by simplifying the whole structure as a two-degree-of-freedom (2DOF) spring-mass system.

On the other hand, the dynamic behaviors of bolt flange connection structures have been studied by numerical methods and experiments [26,27]. Liu et al. [28] studied the dynamic behavior of bolted joints with axial excitation through experiments and three-dimensional finite element simulations. Yang et al. [29] investigated the nonlinear plastic deformation behavior of bolted joints under cyclic loading through analytical method, finite element method and experiments. Somasundaram et al. [30] proposed a finite element model based on Lagrangian smooth particle hydrodynamics method to study the physical destruction and shock wave propagation in the bolted joints. Fu et al. [31] studied the dynamical response of connection of bolted angle steel under sudden gravity loads based on a verification model. Shibue et al. [32] studied the relaxation behavior of bolted flange connection under impact load and analysed the effect of the friction coefficient and initial torque. Xiao et al. [33] studied response of disk spring bolt connection structure excited by step impact loads through theoretical calculation and finite element simulation. He found a variety of vibration state of the nonlinear system when the width variation of input load pulse is not consistent. Shaw et al. [34] investigated the harmonic and sub-harmonic vibrations of a SDOF oscillator. Yang [35] found that the occurrence of sub-harmonic resonance and superharmonic vibration depends on the system parameters and high frequency disturbances.

In this paper, we will establish a three-degree-of-freedom (3DOF) mass-spring model for bolted flange connection structure with shear pin/cone, which can transform the structural nonlinearity problem into the material nonlinear problem. Using this model, we will study the coupling characteristics of response of 3DOF simplified dynamical model. The inheritance of dynamical characteristics between 3DOF model and 2DOF model will be confirmed by studying vibration responses of these systems under impact or circular loads. Additionally, the contour maps of maximum tension response with respect to the inclination angle of shear pin/cone will be illustrated by studying the redirection effects of external loads.