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Vibration responses analysis of an elastic-support cantilever beam with crack and offset boundary

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ABSTRACT

In this study, a finite element model of an elastic-support cantilever beam with crack and offset boundary is established by using mixed elements in ANSYS software. In the proposed model, different contact elements are adopted to describe the breathing effect of crack and offset boundary, and spring elements are used to simulate the elastic support, and the model is also validated by comparing the natural frequencies with those in published literatures. Based on the developed model, the combined effects of the crack and offset boundary on the system dynamic characteristics are studied. The results indicate that the amplitude of double frequency component ($2f_e$) firstly decreases and then increases with the offset values when the crack position is on the opposite side of offset boundary. $2f_e$ may disappear when the crack and the offset boundary locate at a certain position. In addition, the more distant the offset boundary is, the more intense the system nonlinearity becomes. The amplitude of $2f_e$ increases with the offset values when the crack position is on the same side of offset boundary under a constant crack depth and location. Moreover, it also shows some complicated frequency components due to the gradually strengthened nonlinearity of the system with the increasing offset values, and the obvious distortion phenomenon in the phase plane portraits can be observed near the super-harmonic resonance region. This study can provide some basis for the diagnosis of beam-like structures with crack.

1. Introduction

In engineering practice, dynamics analysis of beam-like structures is significantly important in modeling real cases such as aircraft wings, turbine blades, robot arms and many other problems [1–4]. However, the presence of crack could not only cause a local variation of the stiffness, but also affect the vibration behavior of the entire structure to a considerable extent [5–26]. So it is very important to understand the dynamic characteristics of cracked structures. In this respect, many researchers have carried out a lot of research work for the damage mechanism of the cracked cantilever beam-like structures, and the work can mainly be divided into two parts: modeling of the cracked beam and analysis of the crack induced nonlinear vibrations [5,6].

At present, the crack can be described by two types of models: open crack models [7–12] and breathing crack models [13–26]. Many researchers assumed that the crack in structural members is open and remains open during vibration process

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Nomenclature

a	total crack length
b	beam width
d_1, d_2	the distance between the starting point of the crack and the cantilever end, the distance between the offset boundary and the cantilever end
E	Young's modulus
F	impulsive force
F_0	excitation force amplitude
f_c	the first natural frequency of the open crack beam
f_e	excitation force frequency
f_h	the first natural frequency of the intact beam
f_{ni} (i = 1, 2, 3)	the ith natural frequency of the system
h	beam height
k_x, k_y, $k_{\theta z}$	x-direction, y-direction and torsional stiffness
k_c	contact stiffness
L	beam length
p	dimensionless crack location
Δt	duration time of impact loading

Greek symbols

ρ	density
υ	Poisson's ratio

Abbreviations

FE	finite element
FRFs	frequency response functions
2D	two dimensional

[9]. Yang et al. [10] investigated the free vibration of functionally graded materials beams with open edge cracks, and analyzed the influences of the crack parameters (crack depth location) on the natural frequencies of the system. Based on the Green's function, Zhao et al. [11] analyzed a forced vibration of a cracked Euler–Bernoulli beam and revealed that crack parameters (crack depth and location) have great influences on determining the deflections pattern of the system. Although the open crack model is simple, it cannot simulate the crack-induced nonlinear phenomena such as the super- and sub-harmonic resonances due to the crack breathing effect under large excitation loads. In particular, the breathing effect of the crack has been demonstrated by experiments [12–17]. Gudmundson [12] pointed out that the eigenfrequencies concerning breathing crack decrease at a much slower rate than those in the case of an open crack. Andreaus and Baragatti [15] indicated that the simulation results agree well with the experimental results using an actual fatigue crack. Surace et al. [16] developed a method of structural damage identification using the so-called higher order Frequency Response Function (FRFs) which is based on the Volterra series. Chondros et al. [17] evidenced that for a fatigue breathing crack, using an open crack model assumption to interpret vibration characteristics will lead to some incorrect conclusions. Currently, the breathing crack is mainly described based on the following models: square wave models or bilinear stiffness models [13–21], harmonic function models and contact models [22–26].

Based on the breathing crack models, some researchers also analyzed the crack-induced complicated nonlinear vibration behaviors [21–26]. Chati et al. [21] adopted a piecewise-linear two-degree-of-freedom model and used perturbation methods to study the non-linear normal modes of vibration and the associated period of the motion. Ma et al. [22] investigated the nonlinear vibration behaviors of a cantilever beam system with slant crack and analyzed the effects of excitation loads including gravity, excitation force amplitude and the direction of the excitation force, and crack parameters including slant crack angles, crack depths and crack locations on the system vibration responses. Andreaus et al. [24,25] established a two dimensional (2D) finite element (FE) model of a cantilever beam with a breathing crack which adopts a frictionless contact element to describe the breathing characteristics of the crack, and studied the system dynamic characteristics under harmonic excitation. Hu et al. [26] analyzed the nonlinear dynamic characteristics of a cantilever beam with a non-propagating asymmetric fatigue crack subjected to a harmonic load at its tip, and discussed the effects of the excitation frequency, crack depth and crack position on the system vibration responses.

Except that the breathing crack can lead to the stiffness nonlinearity of the system, the asymmetric support can also cause the similar stiffness nonlinearity [27–30]. Andreaus et al. [27] investigated the vibration characteristics of a cantilever beam subjected to the contact of an obstacle, and analyzed how the vibration responses of the system varies when moving the excitation or the obstacle along the beam. Moon et al. [28] established an elastic beam with non-linear boundary which