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Longitudinal vibration of cracked beams under magnetic field ☆

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ABSTRACT

Longitudinal vibration of a cracked beam subjected to the transverse magnetic field is addressed. One dimensional wave theory is used and the crack part of the beam is modelled as by a linear spring, in this analysis. The obtained explicit solution, for clamped-free and clamped–clamped boundary conditions, is illustrated as graphically. It is generally seen that the longitudinal frequencies increase with increase of the intensity of magnetic field. However, the results of the analysis reveal that the transverse magnetic field has a more significant effect on the variation of longitudinal vibration frequency under the clamped–clamped boundary conditions.

1. Introduction

The vibrations of bars containing crack have been investigated by many researchers under the different motivations and the interesting assumptions. Adams et al. [1] determined natural frequencies of longitudinal vibration analytically and experimentally for a free–free bar with a crack. Gudmundson [2] developed an equation for the changes in the natural frequencies by using perturbation method for a bar with free ends and a transverse crack at the centre. Springer et al. [3] examined the free longitudinal vibration of a bar with free ends and two cracks located symmetrically at the centre of the span. Rizos et al. [4] addressed the flexural vibrations of a cantilever beam with rectangular cross-section having a transverse surface crack. Liang et al. [5] developed a method based on measurements of natural frequencies of structures for the detection of crack location and quantification of damage magnitude in a uniform beam under simply supported or cantilevers boundary conditions. The crack location in vibrating simply supported uniform beam is treated [6] for either bending or axial vibrations. The studies done for the identification of the crack location with the ratio of the lower two natural frequencies of the undamaged and damaged rod were extended by Morassi and his colleagues [7–9]. Saez and Navarro [10] presented an analytically approach to the fundamental frequency of cracked Euler–Bernoulli beams in bending vibrations. The flexural vibrations of cracked micro and nanobeams were studied [11]. The natural frequencies and vibration mode of cracked nanobeams on the basis of the nonlocal elasticity theory and Timoshenko beam theory was investigated in [12]. The longitudinal vibration of a cracked nanobeam with different boundary conditions was studied [13] using the nonlocal elasticity theory. The flexural vibrations of cracked nanowires in the presence of surface effects were studied [14,15]. The effects of crack location, crack size, rotation speed and hub radius of a cracked rotating tapered beam on the vibration properties were investigated [16] by using finite element method. Finally, it should be mentioned here an important recent publication found in the present literature. The inverse problem of identifying a single crack in a longitudinally vibrating rod

☆ Dedicated to a distinguished scientist and a good hearted human Prof.Dr.Dr.h.c.M.Cengiz Dökmeci (Istanbul Technical University) in honor of his 80th birthday with the best wishes more happy years to come.

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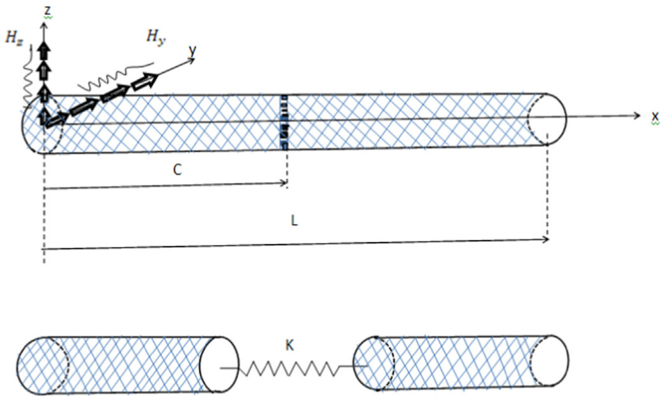

Fig. 1. Sketch of a cracked beam subjected to transverse magnetic field.

having non-uniform smooth profile by minimal frequency data has been considered in [21]. In this work, a numerical code has been developed for the practical application of the damage identification method.

As far as we know, however, there has been no investigation on the longitudinal vibration of beams with crack under magnetic field. However, the many structural elements used in some high industrial applications are subjected to the magnetic field effects, in different manners. The beams as structural elements are frequently encountered in the medical instruments, electrical, aerospace industries, superconducting magnetic energy storages, magnetically levitated vehicles and magnetic forming devices. In these working conditions for the accurate vibration analysis different magnetic fields effects must be considered. In this study, the longitudinal vibration of a cracked beam under the transverse magnetic field is addressed for the clamped-free and clamped–clamped boundary conditions. The cracks are frequently modelled in two ways. One of the well-known models is to use linear spring element and the other is to use reductions in cross-sectional area. Here, the cracks modelled by a linear spring of infinitesimal length separating two section of beam. The main objective of this work is to study the effect of transverse magnetic field on the longitudinal frequency of a cracked beam. The effects of the transverse magnetic field on the longitudinal vibration frequency of a cracked beam under the different crack parameters that reflects the magnitude of crack and the crack locations are presented in detail. The present analysis shows that the effect of transverse magnetic field on the longitudinal vibration of cracked beam significantly varies depending on the boundary conditions.

2. Lorentz force induced by the transverse magnetic field

A magnetically sensitive cracked beam placed in a transverse magnetic field $\vec{H}(0, H_y, H_z)$ is shown schematically in Fig. 1. Here, the crack at location C is simulated by an equivalent linearly elastic spring with coefficient K of infinitesimal length separating two segments of the beam having length L. When neglected the displacement electric current the simplified Maxwell's equations of the magnetic field are expressed as [17–20]

$$\vec{J} = \nabla \times \vec{h}, \quad \nabla \times \vec{e} = -\eta \frac{\partial \vec{h}}{\partial t}, \quad \nabla \cdot \vec{h} = 0, \quad \vec{e} = -\eta \left(\frac{\partial \vec{U}}{\partial t} \times \vec{H} \right), \quad \vec{h} = \nabla \times \left(\vec{U} \times \vec{H} \right) \tag{1}$$

where $\vec{J}$ denotes the electric current density vector, $\vec{h}$ is the perturbation of magnetic field vector, $\vec{e}$ is the electric field vector, $\vec{U}(u, v, w)$ is the beam displacement vector and η is the magnetic permeability (the magnetic permeability values are taken as equal,for the cracked beam and the medium around it), where the mathematical symbols "×" and "•" denote vector and scalar products, respectively, the Hamilton operator ∇ is defined as $\nabla = \frac{\partial}{\partial x}\vec{i} + \frac{\partial}{\partial y}\vec{j} + \frac{\partial}{\partial z}\vec{k}$, and, $\vec{i}$, $\vec{j}$ and $\vec{k}$ are the unit vectors in directions x, y, z.

In the present analysis, the transverse magnetic field is constant and the beam is uniform and that the displacement vector is assumed as $\vec{U} = (u, 0, 0)$, where the longitudinal displacement u only depends on the cartesian coordinate x.

The assumption of constant magnetic field can be seen as a reasonable assumption for steady-state conditions and thin structural elements subjected to the magnetic field.

The Lorentz force is generally calculated by the following relation:

$$\vec{f}_{Lorentz} = \eta \left(\vec{J} \times \vec{H} \right) \tag{2}$$

The Lorentz force occurring due to the transverse magnetic field for the present analysis is obtained as follows [20]:

$$f_{Lx} = \eta \left(H_y^2 + H_z^2 \right) \frac{\partial^2 u}{\partial x^2} \tag{3}$$

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