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International Journal of Engineering Science 41 (2003) 2005–2022

International Journal of Engineering Science

www.elsevier.com/locate/ijengsci

Magnetoelastic modeling of circular cylindrical shells immersed in a magnetic field. Part I: Magnetoelastic loads considering finite dimensional effects

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Received 28 October 2002; accepted 27 January 2003

Abstract

Determination of magnetoelastic loads acting on a perfectly electro-conductive circular cylindrical shell immersed in a uniform applied magnetic field is addressed. The finite dimensional effects related to the finite length and finite thickness of the shell are taken into consideration. Fourier integral method is used to derive the singular integral equations governing the distributed magnetoelastic loads. As special cases, determination of magnetoelastic loads via discarding the thickness effect are obtained from the general formulation, and the magnetoelastic loads of infinitely long shells are derived. Magnetoelastic loads on plate strips or infinite plates are also reduced from the general formulation. To the best of the authors' knowledge, this represents the first work devoted to the analytical determination of magnetoelastic loads on circular cylindrical shells considering the finite length and thickness effects.

1. Introduction

Traditional paradigms of the structural design usually lead to overly redundant material/structural components to be used. Such design paradigms become increasingly unacceptable to aerospace industry. In recent years, the so-called multi-functional material/structure design concept began to receive increasing attention due to its essentially synergetic design process. The underlying concept of such a design paradigm is to exploit multiple properties of materials/

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0020-7225/03/$ - see front matter
doi:10.1016/S0020-7225(03)00134-4

Nomenclature

$\mathbf{f}^{(e)}$	Lorentz force (per volume)
$f_1(R+h,x)$	$\mu_r\mathbf{h}^-$ on the outer surface of the shell
$f_2(R-h,x)$	$\mu_r\mathbf{h}^-$ on the inner surface of the shell
$\mathbf{h}^-$	induced magnetic field outside of the electro-conductive material
$2h$	thickness of the shell
$\mathbf{H}_0$	applied magnetic field
I_0	modified zero-order Bessel function of the first
K_0	modified zero-order Bessel function of the second kind
2ℓ	length of the shell
R	radius of the cross section of the shell
$\mathbf{u}$	displacement vector of the material points within the media
$\delta_D(x)$	Dirac delta function
δ_{ij}	Kronecker delta symbol
μ_e	magnetic permeability of the electro-conductive media
μ_0	magnetic permeability of the free space
μ_r	μ_e/μ_0, relative magnetic permeability
ϵ_e	dielectric constant of the electro-conductive media
ϵ_0	dielectric constant of the free space
ρ_e	free charge density (per volume) in the electro-conductive media
ρ_s	free charge density on the surface (per area)
$\mathbf{J}_s$	surface current
ψ_x	jump of the magnetic field intensity, see Eq. (38)
ψ_r	jump of the magnetic field intensity, see Eq. (39)
$\mathrm{Sign}(x)$	signum function, $=1$ for $x>0$; $=-1$ for $x<0$
$\Delta(x)$	$K_0'(x)I_0(x) - K_0(x)I_0'(x)$
$\jmath$	$\sqrt{-1}$
div	divergent operator
rot	curl operator

structures in such a way that besides its major designated functionality, the same structural component can be used to accomplish at least one more function. Examples of such a design include novel actuators that not only provide the excitation loads, but at the same time can also monitor the operational conditions of itself, such as the damage detection.

In order to support such a design paradigm, it is prerequisite to understand the multi-aspect properties of the material/structures, such as thermo-, electro-, magneto-, elasto-ones. During the last four decades, the influence of applied magnetic field on the mechanical behavior of circular cylindrical shells has been extensively studied (see e.g., [1,2,8–10], and the references therein). However, to the best of the authors' knowledge, the finite dimensional effects in the modeling of magnetoelastic loads, such as the influence of finite length and finite thickness, have not yet been considered in an analytical way.