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DYNAMIC CHARACTERIZATION OF STRUCTURES BY PULSE PROBING AND DECONVOLUTION

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Abstract

This paper outlines the mathematical and computational basis of a procedure for identifying the dynamic behavior of linear structural systems from measurements of transient responses to specified pulses. The dynamic behavior of such systems is fully characterized by dynamic Green's functions, which can be reconstructed by deconvolution from response measurements. The deconvolution involves the solution of an ill-posed integral equation and can be performed by considering an associated Cauchy problem for a partial differential equation in which the measured response is used to define the initial condition. The explosive growth of errors due to contamination of the response by noise is prevented by regularizing the problem so as to minimize a Tikhonov functional. It is shown that infinitely divisible pulses, which include as a particular case the inverse Gaussian pulse, have properties which make it possible to perform continuous deconvolutions and to obtain bounds on errors induced by noise. The effectiveness of the proposed algorithm for reconstructing Green's functions is demonstrated in examples involving dispersive and nondispersive members, and a dispersive structural network that may be representative of a large space structure.

Nomenclature

a	wave propagation velocity (Eq. 29)
A_i	coefficients in Eq. 24
b	response to pulse excitation
b_n	response contaminated by noise
b_{nf}	filtered response data
EI	bending stiffness
g	dynamic Green's function
g_e	Green's function with error due to noise
GA_s	shear stiffness
$H(t)$	Heaviside unit step function
JG_1	torsional stiffness
ℓ	length
m	positive integer
M	bending moment
m_o	mass of hub
$n(t)$	noise
$p(t)$	pulse
s	variable in Laplace transform domain
t	time
T	torsional moment
V	shear force
w	deflection
x	space coordinate
$\{y\}$	state variable vector
β	parameter defining noise distribution
$\delta(t)$	Dirac delta function
ϵ	positive constant (Eq. 13)
ζ	argument in solution of wave equation
η	constant defining hysteretic damping
θ	angular deformation due to torsion
λ	eigenvalues
μ	constant (Eq. 14)
ξ	parameter in Fourier transform space
ρA	mass of beam per unit length
ρI	mass moment of inertia per unit length
$\rho_1 J$	mass moment of inertia about member axis
σ	parameter in inverse Gaussian pulse
τ	time parameter (Eq. 1)
ψ	angular deformation due to bending
ω	regularization parameter (Eq. 15)

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Introduction

It has been pointed out that operating criteria governing automated functions of large space structures, such as directional orientation and figure maintenance, can be met only with distributed active controls[1]. For the controls to be effective, accurate information on the dynamic response of the structure must be available. This is also true of other flexible structures subjected to active controls (e.g., robot arms with noncollocated actuators and sensors[2]). The identification of dynamic properties is therefore essential in such applications.

Owing to the difficulties of earthbound dynamic testing and to the possibility that mechanical properties will change in flight as a result of environmental effects[3], it is desirable to test the structure dynamically in service (on orbit). Dynamic testing can be performed by exciting the structure harmonically over a range of frequencies, and recovering the natural frequencies of vibration and the modal damping parameters from the analysis of the corresponding set of steady state responses. However, under service conditions this method might be impractical; it is desirable to extract the dynamic information being sought in one fell swoop. Since the dynamic Green's function fully characterizes dynamic behavior, this can be done by exciting the structure with an appropriate pulse and extracting the dynamic Green's function of interest from the corresponding transient response.

This paper summarizes recent and current work performed at the National Bureau of Standards concerning mathematical and computational aspects of such a procedure. Reconstructing the dynamic Green's function from the measured response to a