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On the dynamics of non-local fractional viscoelastic beams under stochastic agencies

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Abstract

Non-local viscoelasticity is a subject of great interest in the context of non-local theories. In a recent study, the authors have proposed a non-local fractional beam model where non-local effects are represented as viscoelastic long-range volume forces and moments, exchanged by non-adjacent beam segments depending on their relative motion, while local effects are modelled by elastic classical stress resultants. Long-range interactions have been given a fractional constitutive law, involving the Caputo's fractional derivative. This paper introduces a comprehensive numerical approach to calculate the stochastic response of the non-local fractional beam model under Gaussian white noise. The approach combines a finite-element discretization with a fractional-order state-variable expansion and a complex modal transformation to decouple the discretized equations of motion. While closed-form expressions are derived for the finite-element matrices associated with elastic and fractional terms, fractional calculus is used to solve the decoupled fractional equations of motion, in both time and frequency domain. Remarkably, closed-form expressions are obtained for the power spectral density, cross power spectral density, variance and covariance of the beam response along the whole axis. Time-domain solutions are obtained by time-step numerical integration methods involving analytical expressions of impulse response functions. Numerical examples show versatility of the non-local fractional model as well as computational advantages of the proposed solution procedure.

Keywords: Non local Timoshenko beam, Fractional viscoelasticity, White noise, State variable expansion

1. Introduction

There exists a great variety of non-local beam models in recent literature [1–13], used in a wide range of engineering problems. Certainly a well-established application field is micro- and nano-engineering [12–25], where non-local beam models with various degree of complexity have been proposed as alternative to computationally expensive and sometimes even prohibitive molecular simulations [26], in order to capture size effects which cannot be addressed by a classical local continuum approach [12–25].
Existing non-local beam models typically involve non-local stiffness terms [1–13, 17, 18, 21–25], but also non-local damping terms have been considered in recent studies [28–37]. Typical examples of non-local damping at a macro-scale are those associated with external damping patches applied on beams, surface treatments, long adhesive joints or fibres in composites, which may produce a long-range damped coupling between non-adjacent points of the composite [28–33]. On the other hand, non-local damping models may be useful for capturing damping effects at micro-and nano-scale [34–37], which proved to be relevant in image acquisition via high-speed atomic force microscopes [38] and frequency measurements of vibrating nano-sensors [39]; damping effects in nanostructures have also been observed as a result of humidity and thermal effects [40], external magnetic forces [41], or in tensile test on graphene

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