Two-Stage Identification of a Temperature- and Amplitude-Dependent Nonlinear Fractional Kelvin Model for Viscoelastic Damping Materials

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Viscoelastic materials used in passive damping devices exhibit simultaneous dependence on frequency, temperature, and vibration amplitude, which makes constitutive identification particularly challenging. Temperature effects are commonly described by the time–temperature superposition principle and the Williams–Landel–Ferry (WLF) equation, whereas amplitude dependence can be captured by nonlinear fractional rheological models. However, a compact identification framework capable of accounting for both effects without excessive parameter coupling is still needed.

The present contribution addresses this issue by considering a two-stage identification strategy for a temperature- and amplitude-dependent nonlinear fractional Kelvin model of a viscoelastic damping material. In the first stage, dynamic test data obtained at several temperatures are reduced to a reference temperature by means of horizontal shift factors described by the WLF relation. In the second stage, the parameters of the nonlinear fractional Kelvin model are identified from steady-state force–displacement data using the harmonic balance method. The adopted constitutive law combines a linear elastic term, a cubic elastic nonlinearity accounting for amplitude-dependent stiffness, and a Scott–Blair fractional element representing viscoelastic dissipation.

The proposed decomposition separates thermal shifting from rheological calibration and thus limits the number of parameters identified simultaneously. This is important for maintaining parameter identifiability and numerical robustness when the model includes both fractional-order behavior and nonlinear amplitude effects. Particular attention is focused on the interaction between the fractional rheological parameters and the WLF constants, as well as on the ability of the identified model to reproduce hysteresis loops measured for different excitation frequencies and displacement amplitudes.

The study aims to develop a compact constitutive description suitable for frequency-domain analysis of viscoelastic dampers and damped civil engineering structures. The proposed framework also provides a basis for assessing the practical limits of applying TTSP/WLF-based temperature reduction in nonlinear fractional modeling of damping materials.

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