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Correlation between quasi-static and dynamic experiments for a practical torsional device with multiple discontinuous nonlinearities

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ABSTRACT

Vehicle clutch dampers belong to a family of torsional devices or isolators that contain multi-staged torsional springs, pre-load features, clearances, and multi-staged dry friction elements. Estimation of elastic and dissipative parameters is usually carried out under quasi-static loading and then these static parameters are often assumed when predicting dynamic responses. For the purpose of comparison, this article proposes a new time domain parameter estimation method under dynamic, transient loading conditions. The proposed method assumes a priori knowledge of few nonlinear features based on the design and quasi-static characterization. Angular motion measurements from a component-level laboratory experiment under dynamic loading are utilized. Elastic parameters are first estimated through an instantaneous stochastic linearization technique. A model-based approach and energy balance principle are employed to estimate a combination of viscous and Coulomb damping parameters for seven local (stage-dependent) and global damping formulations for a practical device. The proposed method is validated by comparing time domain predictions from nonlinear models to dynamic measurements. Nonlinear models that utilize the proposed damping formulations are found to be superior to those that solely rely on parameters from a quasi-static experiment.

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1. Introduction

There is an extensive body of literature on the estimation of system parameters [1–9]; see Ref. [1] for a thorough review of prior work as well as a list of over 300 papers. For the purpose of tractability, many researchers assume that nonlinear features or functions are well characterized (or known) before attempting parameter extraction [1]. Alternatively, the “black box” modeling method is used when the underlying physics of a device is truly unknown though ambiguous results may be found [1]. Overall, many of the estimation methods rely on steady-state excitation and assume smooth (differentiable) and/or weak nonlinearities [1]. Prior work [2–8] has often utilized measurements from well-controlled, laboratory or scientific experiments. These experiments [2–8] are intentionally designed to isolate a singular feature of interest, say a spring or dissipative element, and accommodate the necessary instrumentation. Although such methods and experiments are useful

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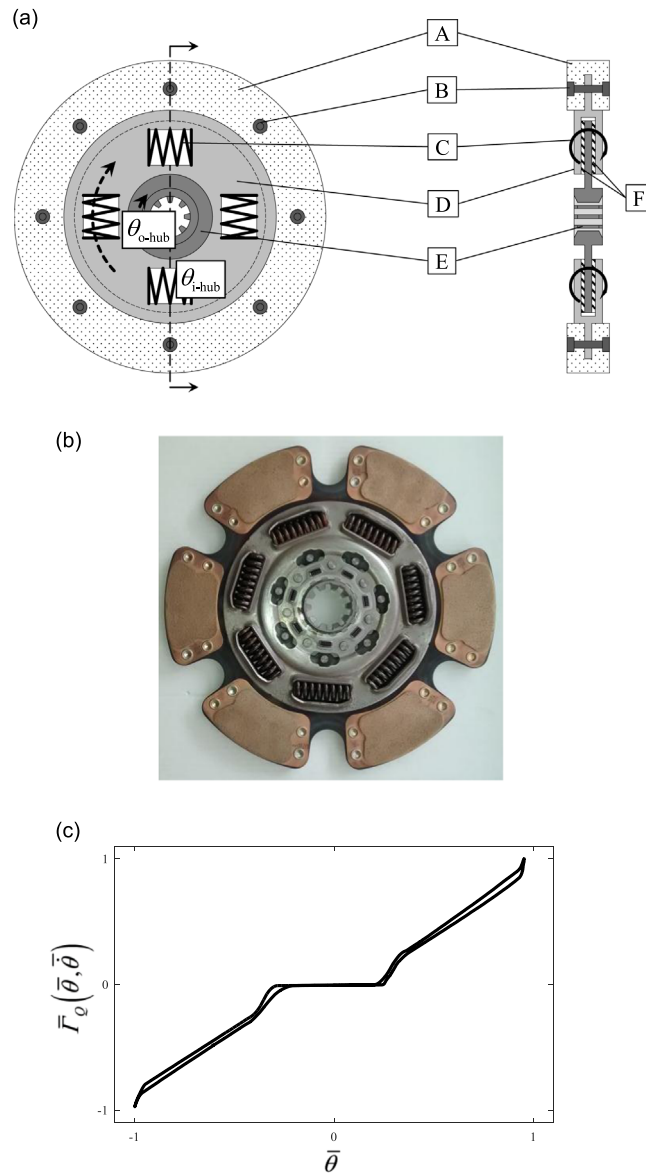


Fig. 1. Illustration of a multi-staged vehicle clutch damper: (a) schematic with parts labeled, (b) photograph of typical production component, and (c) measured (normalized) quasi-static performact curve where $\bar{T}_Q$ is the normalized torque transmitted through the device, $\bar{\theta}$ is the normalized relative angular displacement ($\theta = \theta_{o-hub} - \theta_{i-hub}$), and $\dot{\bar{\theta}}$ is the normalized relative angular velocity. Key for (a): A – flywheel and pressure plate interface; B – rivet; C – multi-staged coil spring; D – outer hub (angular displacement θ_{o-hub}); E – inner hub (angular displacement θ_{i-hub}); and F – multi-staged Coulomb friction element.

for understanding particular nonlinear features, their extension to practical devices [9–21] is severely limited by a lack of controllability found in many applications (say due to variability in manufacturing, assembly, or operating environment). This problem is particularly acute when practical components contain multiple (and yet unknown) discontinuous nonlinearities.

Most real-life components, including nonlinear devices used for vibration isolation [10], are subjected to a wide range of mean operating points and dynamic excitation due to intentional product functions. Even if these devices could be disassembled into separate nonlinear features for individual study, in situ interaction between the built-in features would be lost, and the estimation process would become incredibly complex. It is thus desirable to estimate parameters at the component-level. Nevertheless, this approach has its own unique challenges, such as laboratory space for large-scale experiments, selection of actuators than can provide in situ loading, and location and selection of instrumentation. Accordingly, the primary goal of this article is to propose a time domain method for estimating stiffness and damping properties of a nonlinear torsional isolation device (vehicle clutch damper) that is illustrated in Fig. 1a to b (and further described in Section 2). It has multiple discontinuous nonlinearities (as shown in Fig. 1c) and is often subject to dynamic,

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