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Step-response of a torsional device with multiple discontinuous non-linearities: Formulation of a vibratory experiment

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ABSTRACT

A vehicle clutch damper is intentionally designed to contain multiple discontinuous non-linearities, such as multi-staged springs, clearances, pre-loads, and multi-staged friction elements. The main purpose of this practical torsional device is to transmit a wide range of torque while isolating torsional vibration between an engine and transmission. Improved understanding of the dynamic behavior of the device could be facilitated by laboratory measurement, and thus a refined vibratory experiment is proposed. The experiment is conceptually described as a single degree of freedom non-linear torsional system that is excited by an external step torque. The single torsional inertia (consisting of a shaft and torsion arm) is coupled to ground through parallel production clutch dampers, which are characterized by quasi-static measurements provided by the manufacturer. Other experimental objectives address physical dimensions, system actuation, flexural modes, instrumentation, and signal processing issues. Typical measurements show that the step response of the device is characterized by three distinct non-linear regimes (double-sided impact, single-sided impact, and no-impact). Each regime is directly related to the non-linear features of the device and can be described by peak angular acceleration values. Predictions of a simplified single degree of freedom non-linear model verify that the experiment performs well and as designed. Accordingly, the benchmark measurements could be utilized to validate non-linear models and simulation codes, as well as characterize dynamic parameters of the device including its dissipative properties.

1. Introduction

Practical multi-staged torsional stiffness and friction elements, such as clutch dampers for vehicle drivelines, are designed to transmit variable torque loads while mitigating clearance-induced impact phenomena in gearboxes and other driveline elements [1–7]. Such devices are discontinuously non-linear by nature (intentional or otherwise) as they contain multiple spring and variable friction elements that are spread over several stages depending on the performance requirements of the car or truck powertrain subsystem [1]. Intentional discontinuous non-linear features include clearances, abrupt changes in stiffness, stoppers, pre-load features, and dry friction elements. A typical torque–relative displacement

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($T_D(\theta, \dot{\theta})$) curve is shown schematically in Fig. 1(a) where stage transitions are denoted by Θ and stages are indexed by Roman numeral subscripts. In this example, $T_D(\theta, \dot{\theta})$ is described by a sum of piecewise elastic torque $T_K(\theta)$ and Coulomb hysteresis amplitude $H(\theta)$ (as shown in Fig. 1(b) and (c)). The drive side (subscript +) and coast side (subscript −) are often designed to be asymmetric [1,2]. In high load applications, a multi-staged clutch damper may have a torque capacity of the order of 1000 N m and stiffness ratios between adjacent stages might be as high as 100 or 1000.

It is evident that linear models cannot fully describe the dynamics of multi-staged clutch dampers, especially when considering transient phenomena such as driveline clunk [4]. Development of the appropriate non-linear models requires validation through benchmark time-domain measurements that are often not available. Previous articles have analyzed discontinuous non-linear systems mostly by using mathematical or computational models [2–18]; however, few papers use

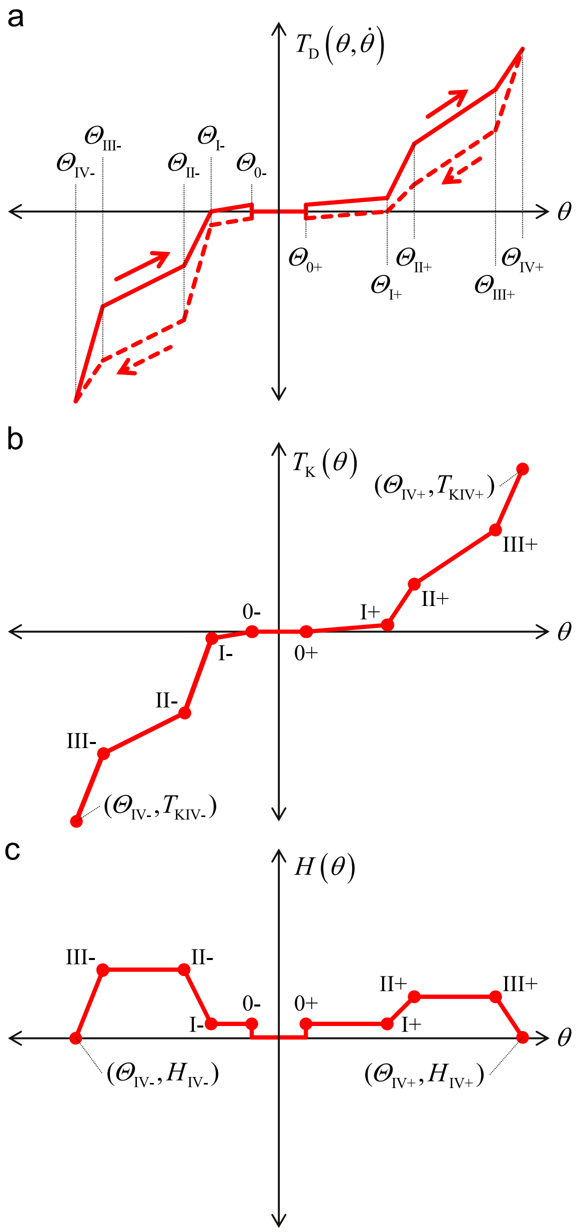

Fig. 1. Typical quasi-static performance curve for a four-stage, asymmetric clutch damper displaying relations for (a) transmitted torque $T_D(\theta, \dot{\theta})$, (b) elastic torque $T_K(\theta)$, and (c). Coulomb hysteresis amplitude $H(\theta)$ where θ and $\dot{\theta}$ are relative angular displacement and velocity. Key: (—) – $\dot{\theta} > 0$, (- -) – $\dot{\theta} < 0$, K – stiffness, H – Coulomb hysteresis, T – torque, and Θ – stage transition (angular). Stages are denoted by subscripts I, II, III, and IV, clearances by subscript 0, and drive/coast sides by subscripts +/−.