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Frequency domain properties of hydraulic bushing with long and short passages: System identification using theory and experiment

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ABSTRACT

Fluid-filled bushings with tunable stiffness and damping properties are now employed in vehicles to improve ride characteristics and to reduce vibration and noise. Since scientific literature on this topic is sparse, a bushing prototype which can provide various combinations of long and short flow passages is designed and built. Several common fluid-filled bushing configurations are experimentally examined for their dynamic stiffness and pressure spectra. Linear time-invariant models (with lumped fluid elements) are proposed for a hydraulic bushing with two parallel flow passages. Next, a model with only a long capillary tube passage (an inertia track) is examined. Further, peak magnitude and loss angle frequencies are analytically found. Several methods for the identification of bushing parameters (up to 50 Hz) are suggested. The linear models are validated by comparing predictions with measured stiffness magnitude and loss angle spectra. Finally, the principal features of a practical device are diagnosed using analytical models and measurements for two excitation amplitudes.

1. Introduction

Elastomeric bushings are widely used in vehicle suspension, body, and engine sub-systems to accommodate for misalignments at the linkage or frame connections for improved handling and ride performance characteristics and to reduce vibration and noise [1–11]. Such devices are often expected to provide a high viscous damping coefficient (c) and stiffness (k) for large amplitude excitations at lower frequencies. Further, lower k and c values are needed for controlling structure-borne noise at moderate to high frequencies [1,2,12]. Since elastomeric bushings cannot satisfy such conflicting requirements, many fluid-filled bushing designs have been developed, as evident from some articles [1,2,12–17] and many patents [18–27]. Even though some patents [18–27] and papers [1,2] claim certain performance features, they provide no analytical justification or even measured stiffness properties. Furthermore, very few scholarly articles [12–16] on hydraulic bushings are available.

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The hydraulic bushing design [1,2,12–27] is somewhat similar to hydraulic engine mounts [28–33], though it significantly differs from conventional hydraulic shock absorbers [34,35]. Nevertheless, several differences in the design, construction, physical mechanisms, and dynamic performance can be observed between hydraulic mounts and bushings. For instance, hydraulic engine mounts are widely used to support vehicle engines and control motion mostly at low frequencies. They are usually equipped with fixed or free decouplers, and the excitation is applied to the top of the mount. The pressure in the lower chamber in the engine mount is usually negligible compared with the upper chamber pressure since the lower chamber is highly compliant. In contrast, fluid-filled bushings do not include the decoupler mechanism(s). In most automotive suspension applications, the outer metal sleeve can be assumed to be fixed, and the excitation is applied to the inner metal part. The two fluid-filled chambers of the bushings are almost identical. Some bushing designs have a leakage (by-pass) path in parallel with the inertia track to communicate fluid under high dynamic deflections [1]. Overall, the dynamic models developed for hydraulic engine mounts cannot be directly applied to fluid-filled bushings due to the differences discussed above. Accordingly, this article will first experimentally study the dynamic properties of a laboratory bushing prototype and then propose new or improved models based on the linear time-invariant (LTI) system theory. The focus of this paper is on the identification of system parameters and an examination of the roles played by long and short flow passages.

2. Problem formulation

2.1. Literature review and unresolved issues

Many fluid filled bushing design features are described in patents [18–27]. For example, Hipsher [18] invented a bushing that consisted of inner and outer metal sleeves and an elastomeric element with two fluid chambers connected by a tube. Konishi [19] proposed a bushing with stopper mechanisms to prevent excessive displacement and fluid passageways that consisted of holes and an annular groove. Kanda [20,21,25] suggested several devices that included a circumferential inertia track and damping means within the fluid chambers, as well as the combinations of two parallel orifice passages with different areas. Thorn [23] introduced a design with an impact absorbing member and an inertia track with flow control means. Tabata [26] added a second dynamic damper for controlling low amplitude vibrations at higher frequencies. Roth and Henry [27] proposed various frequency-range specific inertia track and orifice type designs. Only a few scholarly articles have analytically examined their dynamic responses. For instance, Sauer and Guy [1] briefly presented a design with a by-pass track in parallel with the inertia track for relieving high pressure rises during large impacts; a numerical model is mentioned, but no details or results are provided. Lu and Ari-Gur [12] derived a simple expression for the natural frequency

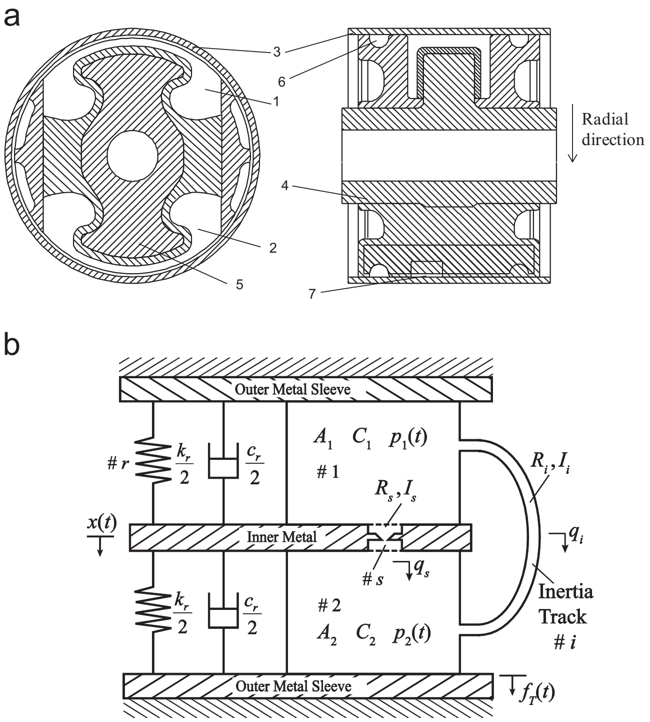

Fig. 1. Fluid-filled bushing example. (a) Typical hydraulic bushing with inertia track and leakage path. Here 1 and 2 are fluid chambers, 3 is outer metal sleeve, 4 is inner metal part, 5 is stopper member, 6 is inertia track, and 7 is leakage path. (b) Fluid model I with long (inertia track, #*i*) and short (#s) flow passages.