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Estimation of impact damping parameters for a cam–follower system based on measurements and analytical model

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ABSTRACT

A new cam–follower system experiment capable of generating periodic impacts is utilized to estimate the impact damping model parameters. The experiment is designed to precisely measure the forces and acceleration during impulsive events. The impact damping force is described as a product of a damping coefficient, the indentation displacement raised to the power of a damping index, and the time derivative of the indentation displacement. A novel time-domain based technique and a signal processing procedure are developed to accurately estimate the damping coefficient and index. The measurements are compared to the predictions from a corresponding contact mechanics model with trial values of damping parameters on the basis of a particular residue; both parameters are quantified based on the minimization of this residue. The estimated damping parameters are justified using the literature and an equivalent coefficient of restitution model is developed. Also, some unresolved issues regarding the impact damping model are addressed.

1. Introduction

Periodic impacts commonly occur in mechanical systems having clearance or backlash; these include geared systems [1–5], cam–follower mechanisms [6–9], and four-bar linkages [10–12]. There is a significant body of literature on such impacting systems employing linear system methods [13,14], non-linear analysis [15], stability investigations [16–18] and energy dissipation analyses [19,20]. However, only a few researchers [15,21,22] have utilized contact mechanics formulation (with an impact damping model) for such systems. The commonly used contact force formulation [21,23–25] is of the following form,

$$F_\lambda = F_k\left(1+\kappa\dot{\delta}\right). \tag{1}$$

Here, F_λ is the contact force (where subscript λ indicates a contact related parameter), F_k is the contact stiffness force, δ is the indentation displacement, and κ is an arbitrary constant. The physical significance of the above formulation is that the contact damping force is assumed to be proportional to the elastic contact force. Additionally, an alternate formulation such as $F_\lambda = F_k + \eta\delta^{0.25}\dot{\delta}$ (where η is a constant) has also been used [22] to represent the contact force during impacts. Overall, there is a clear need to experimentally determine the most appropriate impact damping model, though the direct

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measurement of contact force during an impact remains a challenge. Therefore, the main goal of this article is to propose a new method that would combine measurements and analytical predictions for a cam–follower system to estimate impact damping parameters.

2. Problem formulation

A generalized model for the contact force is proposed below where n is the damping index and β is the impact damping coefficient.

$$F_\lambda = F_k + \beta\delta^n\dot{\delta} \tag{2}$$

The above formulation does not assume a proportionality between the contact stiffness and damping forces. A limiting case of this equation, however, is when the n is equal to the power of δ in F_k, then F_d is proportional to F_k. The extent of hysteresis is controlled by the value of n. Note that the β units depend on the numerical value of n since $\beta\delta^n\dot{\delta}_i$ must have the units of force. The Hertzian contact theory [26] could be used to find F_k since it gives a reasonable estimate of the elastic force as suggested by Veluswami et al. [23]. The values of β and n could then be experimentally determined, though only a limited number of researchers [27] have conducted experimental studies using an impact damping model. Nevertheless, the following key questions remain unanswered: a) will Eq. (2) with experimentally estimated values of β and n be consistent with Eq. (1)? b) Could the hysteresis loop and the contact force be utilized to estimate β and n? c) What is the relative significance of the numerical values of β and n? d) How could one justify the numerical values of β and n, given the literature for a typical mechanical system? e) Is the equivalent viscous damping model appropriate for this problem? Therefore, the scope of this study is formulated to address the above mentioned questions, though it is restricted to impacts with point contacts between two metallic objects.

The key objectives of this article are as follows: (i) design a controlled cam–follower experiment with point contact to measure dynamic forces and motion (in time domain) under periodic impacts; (ii) propose an analogous analytical model for the experiment with contact mechanics formulation; (iii) develop and evaluate a signal processing procedure to experimentally determine β and n without directly measuring the contact force; and (iv) determine an equivalent coefficient of restitution model from the same experiment, and then justify the estimated value(s) of β using the relationship suggested by Hunt and Crossley [24].

The cam–follower system proposed for this study is shown in Fig. 1, which is a representative experiment for impacting mechanical systems, as shown previously [22]. The system consists of a cylindrical steel cam rotating about an axis not passing through its center but parallel to the axis of the cylinder. The follower consists of a long bar of square cross-section attached to a thin cylindrical steel dowel pin, pivoted at its end by a pair of roller bearings, and supported along the vertical direction ($\hat{e}_y$) by a coil spring which is always compressed, thereby forcing it towards the rotating cam. The main assumptions regarding the experiment are: a) the axes of rotation of the cam and the follower remain unchanged at any load; b) the bearings at the follower pivot are frictionless; c) the angular velocity of the cam (Ω_c, subscript c denoting the cam) is constant and unaffected by the impact loads; and d) the coil spring stays vertical during the operation. The following conditions are to be considered in designing the cam–follower experiment to achieve a good estimate of β and n. First, the effect of flexural vibrations of the follower caused by impacts should not affect the measured force and acceleration. Second, the responses should be accurately measured during the impacts which occur within a very short time interval. Finally, the follower must impact with the cam periodically at the rate of once per cam revolution; the need to have this particular condition is explained in Section 5.

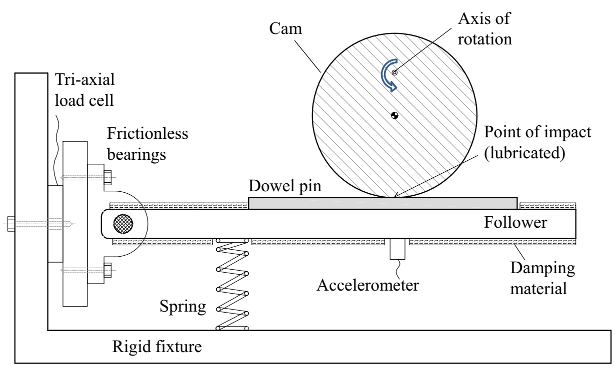

Fig. 1. Cam–follower experiment designed to determine impact damping parameters.

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