Ride Evaluation of Vehicle Suspension Employing Non-linear Inerter

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Keywords: Vehicle suspension, ride comfort, inerter, non-linear, quarter vehicle model.

Abstract. Inerter is a recent element in suspension systems with the property that the generated force is proportional to the relative acceleration between its two terminals, which is similar to the way a spring reacts to relative displacement and a damper to relative velocity. This paper presents the analysis of a non-linear inerter working in parallel to passive spring and damper of a vehicle suspension to evaluate its effect on vehicle’s ride. The non-linear inerter was theoretically capable of switching between on and off states depending on whether or not the suspension deflection was beyond a specified free play. In the study, this behavior was represented mathematically as control law which depended on the relative displacement between the sprung and unsprung masses. A mathematical quarter vehicle model incorporating the non-linear inerter was simulated in MATLAB/Simulink to determine the vehicle responses due to road input in the form of step profile for different combinations of free play and inerter’s on-state proportionality constant called the inerter. Results showed improvements in vehicle ride comfort, as demonstrated by the lower root-mean-squared sprung mass accelerations compared to the ordinary passive suspension with only spring and damper. Additionally, implementation of non-linear inerter gave lower percentage overshoot to step input, indicating better transient response than ordinary passive suspension.

Introduction

It is commonly known that a typical suspension, regardless of its application, consists of two elements, namely the spring and the damper. The spring element serves an important purpose of supporting the static load imposed by the sprung mass, and it reacts to sprung mass displacement to produce sprung force which is responsible for oscillatory response. Meanwhile, the damper element acts as energy dissipater by dampening the response, and it reacts to sprung mass velocity to generate damping force. When working together, these elements serve the fundamental function of a suspension, which is to isolate the sprung mass from undesirable vibrations.

Beside spring and damper, it is possible to have an additional element in suspension that is known as the inerter. Inerter is a recent element in suspension system that reacts to the relative acceleration, similar to the way a spring reacts to relative displacement and a damper to relative velocity. Formally, an ideal inerter is defined as a mechanical, two-node, one-port device with the property that the equal and opposite force applied at the nodes is proportional to the relative acceleration between the nodes [1], as stated mathematically in Eq. 1.

\[ F_{\text{inerter}} = b(\ddot{z}_2 - \ddot{z}_1); \]  

in which \( \ddot{z}_1 \) and \( \ddot{z}_2 \) are the accelerations of the two nodes, \( F_{\text{inerter}} \) is the equal and opposite force, and \( b \) is a constant of proportionality which is termed the inerter [1] and has the unit of kilograms. The passive inerter has been shown to be effective in improving suspension performance in several applications, including building suspensions [2], train suspensions [3] and vehicle suspensions [4]. When applied to suspension systems, the inerter can be arranged in several layouts, but the most