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Use of nonlinear asymmetrical shock absorber to improve comfort on passenger vehicles

M. Silveira [a,*], B.R. Pontes Jr.[a], J.M. Balthazar [a,b]

[a] Department of Mechanical Engineering, São Paulo State University - UNESP, Bauru, 17033-360, SP, Brazil
[b] Department of Applied Mathematics and Computation, IGCE, São Paulo State University - UNESP, Rio Claro, 13506-900, SP, Brazil

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ABSTRACT

In this study the behaviour of two different types of shock absorbers, symmetrical (linear) and asymmetrical (nonlinear) is compared for use on passenger vehicles. The analyses use different standard road inputs and include variation of the severity parameter, the asymmetry ratio and the velocity of the vehicle. Performance indices and acceleration values are used to assess the efficacy of the asymmetrical systems. The comparisons show that the asymmetrical system, with nonlinear characteristics, tends to have a smoother and more progressive performance, both for vertical and angular movements. The half-car front asymmetrical system was introduced, and the simulation results show that the use of the asymmetrical system only at the front of the vehicle can further diminish the angular oscillations. As lower levels of acceleration are essential for improved ride comfort, the use of asymmetrical systems for vibrations and impact absorption can be a more advantageous choice for passenger vehicles.

1. Introduction

The suspension system on a vehicle has a myriad of purposes. The main objective is to isolate the vehicle from disturbances so that the driver can keep control of the vehicle, without endangering his and the passengers' well-being. The disturbances can be caused by irregularities on the road, or caused by loads inherent of the operation of the vehicle, such as acceleration, braking and turning, as well as aerodynamic loads [1]. Therefore, the suspension system should minimize vertical motion, as well as pitch and roll movements, as the vehicle passes over an irregular road, performs turning manouvres, and is accelerated or braked heavily. Apart from these basic operational aspects, the suspension should also provide a good level of comfort for the passengers, minimizing the movements and accelerations imposed on and perceived by them. The level of comfort is increasingly seen as one of the main contributing factors for purchase decision and satisfaction [2]. The loads on the interface between tyre and road are of great importance, not only for the vehicle performance, but also for road degradation. Appropriate suspension design may considerably reduce damage inflicted by the vehicle on some types of roads [3,4]. The cost of the suspension system should also be kept at a minimum in order to improve the commercial attractiveness of the vehicle. Therefore, these many purposes are generally contradictory [5], making the design of the system a global optimization process.

The usual elements of a suspension system are an elastic spring, responsible for the stiffness of the system and acting as a transformer of kinetic energy into elastic potential energy, and a shock absorber (damper), responsible for dissipating energy from the vibrations. These are called passive elements, as they do not require an external power source and their characteristics are constant. Although passive suspension systems are the most common in passenger vehicles, it is well

* Corresponding author. Tel.: +55 1431036119.
E-mail address: m.silveira@feb.unesp.br (M. Silveira).

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known that they are not ideally suited to the whole range of operational conditions and purposes [1,5–7]. A well-known example is the case of a vehicle tuned for comfortable ride over an irregular road, having the drawback of excessive roll and pitch movements, while cornering and breaking, respectively.

One method to try to comply with so many disparate requirements is to use an active system, which involves an input of energy (e.g. a system with compressors, hydraulic pumps and actuators) and a control algorithm [1,5–8]. Research into active suspensions for passenger vehicles started in the 1970s, with the first production and competition cars using the technology in the late 1980s. The rapid advance of electronics benefited the development and application of such active systems, including many types of sensors and actuators [1,9]. Despite having very good efficacy, which results in high ride comfort, active suspension systems result in a considerable increase in complexity, involving sensors, actuators, considerations of power consumption, weight, packaging and development of control strategies, all ultimately increasing the cost of the final product [1,5,6,10]. Because of these drawbacks, they are still not widely applied to passenger vehicles.

Another method devised to improve the performance of vehicles is the semi-active suspension, which usually comprises passive elements which are tuned according to the conditions the vehicle experiences at a particular moment. The semi-active systems can provide better performance than passive systems, although requiring less power and being less complex than active systems [1,5]. Implementation of this type of system includes, for example, use of tuneable dampers, mangeto- and electrorheological actuators [5–7].

The level of comfort for passengers depends on the amplitude and frequency of vibrations, as well as on direction, location and length of exposure [11,12]. Severe vibrations, besides being the cause for discomfort, can be the cause for occupational health disorders [6]. Vibrations reach the passengers' body mainly through the seat, and also through the steering wheel and floor [2]. Careful design of seats and good understanding of the interactions between seats and the body are fundamental for improved isolation of vibration [6,11,13]. The most common methods used worldwide for measurements of vibrations affecting humans are the ones described in the ISO 2631-1, BS 6841, VDI 2057 and the method of average absorbed power (AAP) [14,15]. These methods define objective indices based on vertical and angular accelerations, and are used for the design of on-road [2,16,17] and off-road [14,15,18,19] vehicles, and also for specific parts such as the seats [6,11,13].

The irregularities on the road cause disturbances which are classified as shock or vibration [1]. The first is related to discrete disturbances, usually associated with higher amplitudes, such as a bump or a pothole. The latter is related to continuous irregularities, such as an unpaved road. Both types have different requirements for the suspension system.

The classic theory of mechanical vibrations usually considers a viscous damper which acts in a continuous and proportional way to the required velocity, i.e., it acts in a linear and symmetrical manner [20,21]. The behaviour of this configuration is demonstrated by the isolation or suppression of the harmonic inputs in the stationary regime. But when the absorber device is also exposed to transients which come from impact situations, this configuration is not the one that shows the best performance. Due to this fact, one solution was the adoption of a viscous damper that acts in an asymmetrical way, i.e., it has larger dissipation effect in the opposite way of the usual impact direction. In this work, this is called nonlinear asymmetrical viscous damper. The damper has less action during the impact and the energy is stored initially in the elastic element, so it can be dissipated in the next oscillations in a longer time period, after the first instants of the impact.

Suspension systems with nonlinear elements have been studied by several authors, including nonlinear springs and nonlinear dampers [10,22,23]. On the specific case of asymmetrical dampers, Rajalingham and Rakheja [24] showed that the asymmetrical dissipative effect causes a dislocation of the mean position of a vibrating mass, denominated packing or jacking down. Shekhar et al. showed that the dampers have more responsability on this than the springs [25], and the difference between linear and nonlinear elements is more pronounced for more severe shock loads [26].

Motivated by the necessity to find relatively simpler ways to improve ride comfort for passengers, in this study the asymmetry of shock absorbers is investigated and its effects on the dynamic response of vehicles undergoing shock inputs from the road are analysed, with focus on passenger comfort. The modelling and the behaviour of two shock absorber configurations, one with symmetrical viscous damping and one with asymmetrical viscous damping, are presented. Both types of absorbers were analysed under different profiles of road displacement and simulated using quarter-car and half-car models.

The paper is organised as follows: Section 2 introduces both models of shock absorbers (symmetrical and asymmetrical) used for the simulations, together with the quarter-car and the half-car model. This section also includes a description of the types of input, introduces the performance indices used in the analyses and lists the parameters used for all models. Section 3 contains the results for the quarter-car model, while Section 4 contains the results for the half-car model. The analyses use the different standard inputs and include variation of the severity parameter, the asymmetry ratio and the velocity of the vehicle. The performance indices and the accelerations are used to assess the efficacy of the asymmetrical systems. Section 5 introduces the front asymmetrical half-car model and compares this model to the asymmetrical one. Finally, conclusions are drawn and suggestions for future work are given.

2. Shock absorber models

There are many models suited for the dynamical analysis of vehicles, varying from simpler models to more sophisticated ones. Lower order models with lumped parameters are very common for analysis of the vertical dynamics. Quarter-car