Verification and Optimization Advantage of Inerter Devices Apply to Grounded Vehicle Dynamics

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Abstract

Passive, semi-active and active suspension systems have been utilized to improve ride comfort of vehicles and their effectiveness has also been demonstrated. In the facts, a suspension system needs to be soft to insulate against road disturbances and hard to insulate against load disturbances. It cannot achieve with a traditional passive suspension that only considered to the stiffness and damper. To achieve it, several control methods have been proposed, but most of them relate the active suspension [1,2,3]. In this study, we propose some new designs, which have some advantages for suspension system by improving vehicle oscillation. We optimize design of model based on the minimization of cost functions for displacement, tie deflection with constraint function of suspension deflection limitation and the energy consumed by the inerter. The paper clarifies some issues related to suspension system with inerter to reduce sprung mass displacement and tire deflection in quarter-car model. In this paper, we integrate some kinds of suspension system with inerter on quarter-car models. The advantage of research is integration a new mechanism, the inerter; this system can improve the vehicle oscillation on quarter-car model with different parameters that shows the benefit of the inerter in proposal suspension system.

Comfort Specifications: The comfort characteristics are considered, it mainly related to displacement, chassis vibration, noise, etc. It has an impact on the driver reaction time, accuracy, situation evaluation and decision abilities, which makes this objective particularly active in the automotive community. According to these kind of models, they indicate some sensitive frequency zones related to the heart, the head, etc. having resonance or gain amplifications around some specific frequencies according to different disturbances such as the road irregularities [4].

In this study, the comfort is not directly discussed, but evaluated through the chassis analysis as sprung mass displacement. The comfort feeling analysis is performed by analyzing some specific frequencies of the vertical behavior of the quarter-vehicle model. We focus on the analysis of simpler variables behavior with respect to road unevenness, such as vertical acceleration $\ddot{Z}_s$ and displacement Z_s of the chassis. Then an improvement on these variables will imply comfort improvement with mathematical objective is:

$$\min \ddot{Z}_s(t) := \min Z_s(t) \quad (1)$$

Road-Holding Specifications: Road-holding is a vehicle property which characterizes the ability of the vehicle to keep contact with the road and maximize wheel tracking to road unevenness. It is very simplified manner, the longitudinal (F_{tx}) lateral (F_{ty}) forces of each tire as follows:

$$F_{tx} = F_n\mu_x; \qquad F_{ty} = F_n\mu_y \quad (2)$$

Where μ_x and μ_y are the nonlinear functions, dependent on the slip ratio, the slip angle and the road roughness characteristics.

These forces are also affine functions of F_n, the normal load, defined as:

$$F_n = (M_s + M_u)g - k_t(Z_u - Z_r) \quad (3)$$

Where M_s and M_u are the sprung and unsprung masses, k_t is the vertical tire stiffness characteristic and tire deflection $Z_{t\text{-}def} = Z_u - Z_r$

Because $(M_s + M_u)g > 0$ and $k_t > 0$ then: F_n max when tire deflection $Z_{t\text{-}def}(t) = Z_u(t) - Z_r(t)$ go to minimization.

Suspension Limitations: when evaluating a suspension system and its associated control algorithm, to take into account the static suspension stroke limitations $Z_{sus} = Z_s - Z_u$ which should always remain in between the limitations defined by the technology, i.e. then:

$$\min Z_{sus} \le Z_{sus} \le \max Z_{sus} \quad (4)$$

Where min Z_{sus} an max Z_{sus} are the suspensions deflection limits. This constraint is very important for practical applications, in order to preserve the mechanical suspension system.
To improve vehicle oscillation, this study proposes a design of passive suspension system taking with new component element named "inerter" into consideration the both sensitive of the sprung mass and tire deflection vehicle behaviour when have road disturbance [5]. It can improve both displacement and tire deflection of vehicle proposed by optimizing the modal parameters of suspension and tire. To verify the effectiveness of the proposed method, a quarter-car model which has variable stiffness, damping and inerter in suspension system is constructed and the numerical simulations are carried.
For modelling of an inerter, it was defined to be a mechanical two-terminal, 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. For example, the gear type inerter mechanism including a gear set and rack, it has two terminals at the rack and the base body. The dynamic equation of an inerter is derived as F=b*a, wherein F, b and a represent the applied force, the inerter coefficient (called inertance) and the relative acceleration of two terminals, respectively. The inertance is calculated from the radius and inertia of flywheel. Another objective is presented to reduce friction force and system energy dissipation is screw type inerter mechanism. It can be reduce conventional backlash general by gear transmission [6]. In other hands, hydraulic type inerter is mechanism which comprises a hydraulic cylinder. A hydraulic motor connected to hydraulic cylinder with an output shaft for converting the linear motion to rotary motion and an inerter body disposed on the output shaft. This system subjects to high external force loads and controllability [7].
Let focus attention first on the familiar two-terminal modeling elements: spring, damper and inerter. Each is an ideal modeling element, with a mathematical definition [8,9,10]. It is useful to discuss on mechanical networks, which give some hint toward the inerter idea, in order to highlight the new passive suspension system.

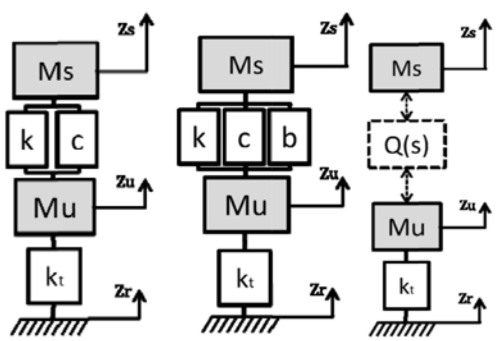

Figure 1: The Base, Parallel and Quarter-car model with suspension function represented in Laplace transformed in respectively

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