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ORIGINAL ARTICLE

A universal suspension test rig for electrohydraulic active and passive automotive suspension system

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Abstract A fully active electro-hydraulic and passive automotive quarter car suspensions with their experimental test-rigs are designed and implemented. Investigation of the active performance compared against the passive is performed experimentally and numerically utilizing SIMULINK's Simscape library. Both systems are modeled as single-degree-of-freedom in order to simplify the validation process. Economic considerations were considered during the rig's implementation. The rig consists of two identical platforms fixed side by side allowing testing two independent suspensions simultaneously. Position sensors for sprung and unsprung masses on both platforms are installed. The road input is introduced by a cam and a roller follower mechanism driven by 1.12 kW single phase induction motor with speed reduction assembly. The active hydraulic cylinder was the most viable choice due to its high power-to-weight ratio. The active control is of the proportional-integral-differential (PID) type. Though this technique is quite simple and not new, yet the emphasis of this paper is the engineering, design and implementation of the experimental setup and controller. A successful validation process is performed. Ride comfort significantly improved with active suspension, as shown by the results; 24.8% sprung mass vibration attenuation is achieved. The details of the developed system with the analytical and experimental results are presented.

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1. Introduction

The three available classifications of the suspension system (Fig. 1) are passive, semi-active and active suspension systems, and this classification depends on the ability of the system to absorb, add or extract energy. The passive suspension (Fig. 1a) is the most commonly used due to its simplicity, robustness and low price. It has limited performance because its components can only store or dissipate energy and can never create energy which cannot satisfy both the comfort and handling requirements under varying road conditions. Most passive suspension systems employ spring with hydraulic or pneumatic shock absorber. The damping force created by shock absorbers is based on converting vibration energy into heat, then dissipating it to surroundings. This leads to change in oil viscosity which influences the damping characteristics [1].

Traditional automotive suspension designs have been a compromise between three conflicting criteria which are road handling, load carrying, and passenger comfort. Good ride comfort requires a soft suspension but it will be sensitive to changes in applied loads. Good handling requires a suspension

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Nomenclature

ER	electrorheological	NG6	nominal size 6 valve
DOF	degree of freedom	PDF	pseudo derivative feedback
HILS	hardware in the loop	PID	proportional integral derivative
LPT	linear position transducer	PWM	pulse width modulation
MR	magnetorheological	QC	quarter car

setting neither stiff nor soft. The conventional passive suspension involves spring and damper with constant coefficients [2]. Due to these conflicting demands, suspension design should compromise between these two problems as shown in Fig. 2 [3].

Nowadays picking a car became such a prolonged and tiring process. Cars were previously chosen according to their size and power but now as people spend a considerably long time in their cars, comfort became one of the major aspects of choosing one's vehicle. Hence, all of car manufacturers are competing in providing the utmost level of comfort by modifying their suspension systems to cope up with the road bumps and potholes. Although the excitations arising from road roughness primarily affect the vehicle ride comfort, it is the input over which vehicle design engineers and vehicle drivers have the least amount of control. There are three different models for potholes which are smooth, non-smooth and statistical potholes [4]. Thus automotive manufacturers started to explore alternatives for the passive suspension to eliminate the above mentioned compromise and that is when the principle of active and semi-active suspensions started to be increasingly employed in high-end luxury cars as they improve comfort and stability despite their high price and power consumption [5].

The semi-active (Fig. 1b) was first introduced by Karnopp and Crosby in the early 1970s, [6] based on the well-known skyhook control. The damping coefficient is varied by variety of methods but still the suspension system can only dissipate the road forces and can't add additional force to the system. With the right control system, the passive suspension's compromise can be reduced resulting in a smart system making cars comfortable regardless of the road they are driven on. Choi et al. [7] and Yao et al. [8] discussed the design and control of the Magnetorheological (MR) dampers via several techniques while utilizing Hardware-in-the-loop-Simulation (HILS) methodology. Another type of semi-active suspension utilized the Electro-rheological (ER) damper system. Choi et al. [9] performed field test to evaluate performance characteristics of a semi-active ER suspension system associated with skyhook controller. They demonstrated that ride comfort and steering stability of the vehicle were improved. Cao et al. [4] showed that semi-active systems have advantages over active systems, including low power requirements, simplicity, ease of implementation and low-cost.

Active suspension systems (Fig. 1c) employ a controllable actuator between the sprung and unsprung masses. This actuator is able to both add and dissipate energy to and from the system. The early studies on active suspensions performed by Hrovat [10] included numerous approaches such as modal analysis, eigenvalue assignment, model order reduction, nonlinear programming, multi-criteria optimization, and optimal control. Classic control methods have also been considered,

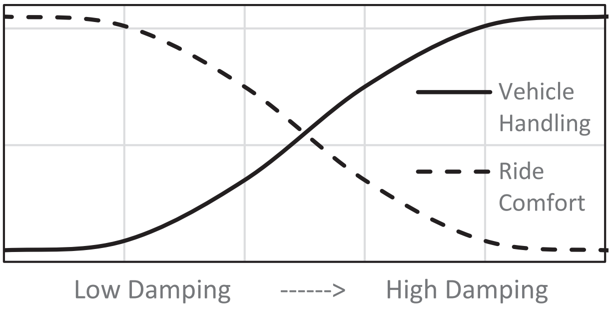
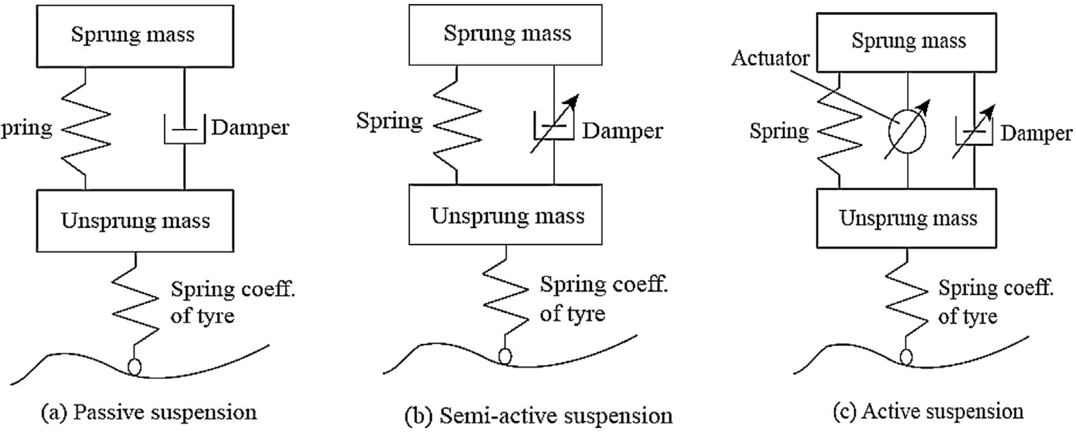


Figure 2 Damping compromise for passive dampers.



(a) Passive suspension (b) Semi-active suspension (c) Active suspension

Figure 1 Suspension system classifications.

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