A Comparison of the Performance and Power Requirements for Switchable Damper and Active Suspension Systems

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***Abstract*— In this paper, the full-car model for passive suspension system (PSS), switchable damper suspension system (SDSS) and active suspension system (ASS) are compared in terms of their relative power requirements and ride performance. The linear quadratic regulator (LQR) and Fuzzy logic control (FLC) strategies are used for the system behavior and compared relative to the PSS. The PSS, SDSS, and ASS are evaluated in terms of ride performance criteria. The optimal suspension parameters values are evaluated. The results revealed that the ASS with the LQR control strategy gives better ride performance compared with PSS and SDSS. The ASS with the FLC strategy gives the best ride performance compared with the ASS using LQR control, and SDSS with LQR and FLC strategies. The mean power demand ($\overline{\mathbf{P}}_{\mathbf{Dem}}$) and dissipation ($\overline{\mathbf{P}}_{\mathbf{Diss}}$) within the suspension systems are evaluated and discussed.**

***Index Terms*— Active suspension system (ASS), Fuzzy control (FLC), LQR control, Ride performance, Switchable damper (SD).**

I. INTRODUCTION

THE ASS is one in which a hydraulic or pneumatic actuator is utilized in the suspension system in conjunction with or as a replacement for the PSS. It is evident that ASS possess considerable potential for improving vehicle ride and handling compared with other intelligent suspension systems [1-2]. In spite of the performance results of the theoretical ASS studies, its utilization is limited to some prototype vehicles due to its increased cost, complexity coupled with high energy consumption [3-4]. Soliman et al [5] developed a mathematical model for the twin spring system using a half-car model for PSS to study the effect of front and rear spring stiffness on the vehicle dynamics. Their results revealed that the measured values of the vertical acceleration and suspension working space were 8% to 10% higher than those predicted. Giliome et al [6] concerned their study with the development of a semi-active hydro-pneumatic spring and damper system to enhance the ride comfort and handling. A test-rig of single degree of freedom (DOF) with a body mass of 3 tons was used. They concluded that by utilizing the semi-active hydro-pneumatic spring with a high and low spring rate a suspension system that is optimized for both handling and ride comfort can be achieved. Heo et al [7] concerned their study with the continuously variable damper; the impact of the damper characteristics changes upon ride comfort and driving safety have been examined via simulation. Their results indicated that the soft damping force limit affects the performance of the semi-active suspension system (SASS) more than the hard limit. Hence the design parameters that affect the soft damping limit must get more attention than others.

Soliman [8] analyzed the effect of the SDSS on vehicle ride quality control. The simulation results indicated that the SDSS with adaptive control is superior compared with the PSS. An improvement of 20% of the root mean square (RMS) of vehicle vertical acceleration is achieved using the SDSS with adaptive control. The power dissipation ($\mathrm{P_{Diss}}$) in suspension relative to power consumed in rolling resistance for the SDSS is discussed. Other researchers studied the effect of SDSS, SASS, and ASS on the vehicle ride performance [9-14], however, their research concentrated on the linear optimal control theory and adaptive control using a quarter or half-vehicle model. In this paper, the LQR and FLC strategies are used for the system's behavior using the full-car model. Also, the $\overline{\mathrm{P}}_{\mathrm{Dem}}$ and $\overline{\mathrm{P}}_{\mathrm{Dem}}$ within the suspension systems are assessed and discussed.

II. MATHEMATICAL MODEL

1) Three-setting SDSS Model

The SDSS for a full-car model is shown in Fig. 1.

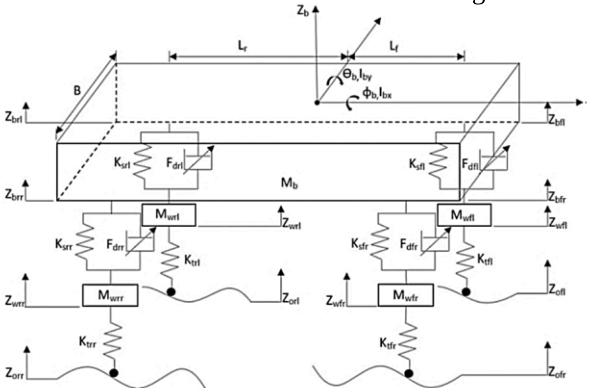

Fig. 1. SDSS for full-car model

The equations of motion (EOM) can be written in the matrix form as follows;

$$\begin{bmatrix} M_b & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & I_{bx} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & I_{by} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & M_{wfr} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & M_{wfl} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & M_{wrr} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & M_{wrl} \end{bmatrix} \begin{bmatrix} \ddot{z}_b \\ \ddot{\phi}_b \\ \ddot{\theta}_b \\ \ddot{z}_{wfr} \\ \ddot{z}_{wfl} \\ \ddot{z}_{wrr} \\ \ddot{z}_{wrl} \end{bmatrix}$$

$$+\left[\begin{matrix} c_{sfl}+c_{sfr}+c_{srl}+c_{srr} & \frac{B}{2}.c_{sfl}-\frac{B}{2}.c_{sfr}+\frac{B}{2}.c_{srl}-\frac{B}{2}.c_{srr} & \cdots \\ \frac{B}{2}.c_{sfl}-\frac{B}{2}.c_{sfr}+\frac{B}{2}.c_{srl}-\frac{B}{2}.c_{srr} & \left(\frac{B}{2}\right)^2 c_{sfl}+\left(\frac{B}{2}\right)^2 c_{sfr}+\left(\frac{B}{2}\right)^2 c_{srl}+\left(\frac{B}{2}\right)^2 c_{srr} & \cdots \\ -L_f.c_{sfl}-L_f.c_{sfr}+L_r.c_{srl}+L_r.c_{srr} & -\frac{B}{2}L_f.c_{sfl}+\frac{B}{2}L_f.c_{sfr}+\frac{B}{2}L_r.c_{srl}-\frac{B}{2}L_r.c_{srr} & \cdots \\ -c_{sfr} & \frac{B}{2}.c_{sfr} & \cdots \\ -c_{sfl} & -\frac{B}{2}.c_{sfl} & \cdots \\ -c_{srr} & \frac{B}{2}.c_{srr} & \cdots \\ -c_{srl} & -\frac{B}{2}.c_{srl} & \cdots \end{matrix}\right.$$