SEMI-ACTIVE CONTROL OF HALF CAR VEHICLE MODEL TRAVERSING ROUGH ROAD WITH MAGNETO RHEOLOGICAL SUSPENSION

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Summary The performance of magnetorheological (MR) dampers used as semi-active suspension devices in half car vehicle models in improving the ride, road holding and suspension working space characteristics of the vehicle is investigated. The MR damper is modelled using Bingham and modified Bouc-Wen model. To validate the modified Bouc-Wen model, a twin tube MR damper is designed and fabricated. The MR damper used in half car vehicle model is a hypothetical analytical damper. The MR damper model parameters are determined optimally so that the performance of the semi-active suspension matches with the performance of fully active suspension based on Linear Quadratic Regulator (LQR) control by minimizing the mean square difference between the vehicle responses namely sprung mass acceleration, suspension stroke, road holding and control force corresponding to MR damper and LQR control. It is observed that performance of half car vehicle model with MR damper suspension system performs better than passive suspension system and closer to the performance of active suspension system.

INTRODUCTION

Semi-active suspensions using variable orifice dampers, variable friction devices, tuned liquid dampers and variable stiffness devices, electrorheological (ER) and magnetorheological (MR) fluids have been used to control the vibration response of vehicles traversing rough roads. Karnopp $et\ al.$ [1] were the earliest to propose semi-active suspension systems as an alternative to active suspension systems. They proposed sky-hook system concept for improving the vibration isolation performance of the suspension by use of a variable rate damper. Georgiou $et\ al.$ [2], Gopala Rao and Narayanan [3] are some of the few who have also used the concept of semi-active suspensions using sky-hook control to control vehicular vibration and optimized the parameters of the sky-hook suspension system. Prabakar $et\ al.$ [4] presented a new method of designing an optimal H_∞ controller with preview using a Non-dominated Sorting Genetic Algorithm II (NSGA II) for a half car vehicle model with MR damper.

In this paper, the use of MR dampers as semi-active suspension devices in vehicle applications is further investigated. The hysteretic behavior of the MR dampers is modeled by the Bingham and modified Bouc-Wen models [5]. A new method of enhancing the semi-active suspension performance of the MR dampers to the levels of performance of active suspension systems based on H_∞ control and the Linear Quadratic Regulator (LQR) theory is proposed.

DESIGN, FABRICATION OF MR DAMPER AND EXPERIMENTAL DETAILS

A twin tube MR damper was designed and fabricated (Figure 1). The fabricated MR damper is tested for its dynamic behavior which includes force vs time, force vs displacement and force vs velocity characteristics. It is tested for a stroke length of $\pm$ 15 mm at 1.67 Hz, varying the electric current from zero to 1.5 A.

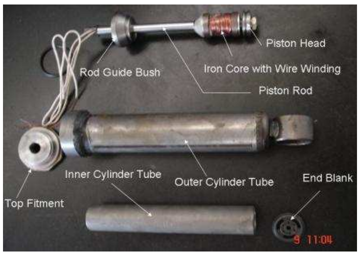

Figure 1. Fabricated MR components

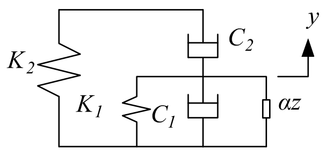

Figure 2. Modified Bouc-Wen Model

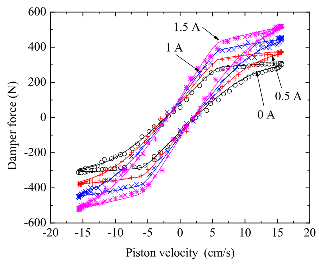

Figure 3. Force vs Velocity

The dynamic behaviour of the MR damper is modelled by the modified Bouc-Wen model shown in Figure 2. It consists of a linear viscous damper with damping coefficient C_2 connected in series and a spring K_2 connected in parallel with a normal Bouc-Wen model. The MR damper model parameters are determined to fit the hysteretic behaviour predicted by the model in terms of the force-time, force-displacement and force-velocity characteristics with experimental results obtained doing a dynamic test for different input currents. The parameters are determined by a multi-objective optimization procedure using the NSGA II in combination with the pareto optimal scheme minimizing the squared error between the experimental force and the model force generated by the MR damper corresponding to zero input current and maximum input current of 1.5 A. The agreement between the experimental and theoretical hysteresis curves for these parameters are in excellent agreement as shown in Figure 3 for different input currents. The values of the parameters of the MR damper thus obtained are K_1 = 12.068 N/cm; α_a = 41.792 N/cm; K_2 = 10.177 N/cm; α_b = 15.917 N/cmA; C_{1a} = 3.9968 Ns/cm; C_{2a} = 43.074 Ns/cm; C_{1b} = 4.9906 Ns/cmA; C_{2b} = 15.414 Ns/cmA; β = 0.0817 cm^{-1}; γ = 11.839 cm^{-1}; A_1 = 75.676.

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HALF CAR VEHICLE MODEL

The schematic of the half car model with MR and active suspension systems are shown in Figures 4 and 5 respectively. The MR damper as before is modelled by the Bingham and modified Bouc-Wen models.

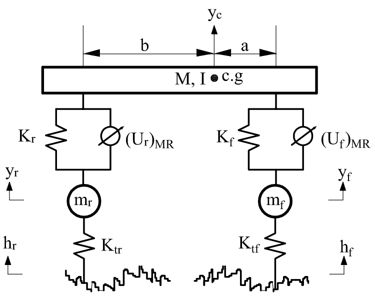

Figure 4. Half car vehicle model with MR suspension system

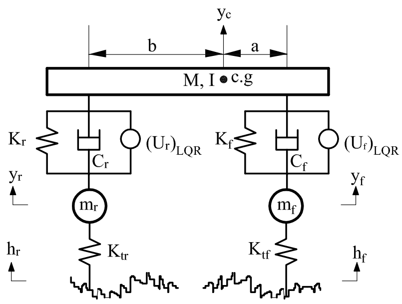

Figure 5. Half car vehicle model with active suspension system

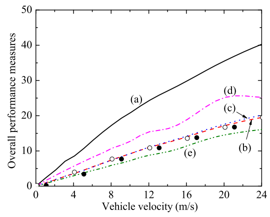

Figure 6. Overall performance measures.

The generalized state space representation of half car vehicle model is given by

$$\{\dot{x_a}\} = [F]\{x_a\} + [G]\{U\} + [D_1]\{w(t)\} + [D_2]\{w(t - t_w)\} \tag{1}$$

where $[F]$, $[G]$, $[D_1]$ and $[D_2]$ represent system matrix, control matrix and excitation matrix corresponding to the front and rear wheels respectively. The control matrix $[G]$ is zero for the passive and MR suspension system. The control force $(U_f)_{LQR}$ and $(U_r)_{LQR}$ are the LQR control forces corresponding to the front and rear suspension systems. The performance index can be expressed as

$$J = \lim_{T\to\infty} \frac{1}{2T} \int_0^T (\rho_1 J_1 + \rho_2 J_2 + \rho_3 J_3 + \rho_4 J_4 + \rho_5 J_5 + \rho_6 J_6 + \rho_7 J_7 + \rho_8 J_8)dt \tag{2}$$

The optimal MR damper parameters modelled using Bingham and modified Bouc-Wen model are also obtained using the multi-objective optimization technique by minimizing the error between the response obtained from the MR suspension system and the response obtained from the active suspension system based on LQR control. The half car vehicle model with the following parameters is considered as an example. M = 1200 kg, m_f = 75 kg, m_r = 80 kg, I = 1800 kg m^2, K_f=30 kN/m, K_r=30 kN/m, C_f = 400 Ns/m, C_r = 450 Ns/m, K_{tf} = 300 kN/m, K_{tr} = 300 kN/m, a = 1.011 m , b = 1.803 m and the road parameters used in the analysis are α_r=0.45 rad/m and σ^2=3×10^{-4} m^2. The optimal modified Bouc-Wen model parameters for the front suspension system are given by, K_{1f} = 641.27 N/m, K_{2f} = 625.35 N/m, C_{1f} = 920.08 Ns/m, C_{2f} = 2707.2 Ns/m, α_{1f} = 4912.2 N/m, β_{1f} = 88.55 m^{-1}, γ_{1f} = 521.22 m^{-1}, A_{1f} = 100.16 and for the rear wheel are given by, K_{1r} = 782.72 N/m, K_{2r} = 504 N/m, C_{1r} = 946.56 Ns/m, C_{2r} = 3862 Ns/m, α_{1r} = 3737.7 N/m, β_{1r} = 121.85 m^{-1}, γ_{1r} = 526.84 m^{-1}, A_{1r} = 118.43. The response of the half car vehicle model with MR suspension system based on optimal Bingham and modified Bouc-Wen model parameters are obtained from these optimal values and the weighting constants used for the active suspension system are as follows ρ_1 = 1, ρ_2 = 2, ρ_3 = 1e2, ρ_4 = 1e3, ρ_5 = 1.5e4, ρ_6 = 5e4, ρ_7 = 1e-8, ρ_8 = 1e-8, R = 0.001. It is observed from overall performance (Figure 6) that semi-active suspension system performance (b and c) performs better than passive (a) and active suspension with Kalman filter (d) and close to the performance of the LQR control (e).

CONCLUSION

The performances of half car vehicle model with MR suspension are sought to be enhanced to the levels of performance of an active suspension based on a stochastic optimal control theory such as the LQR with full state and limited state feedback. This is achieved by minimizing the mean square difference of the response measures like sprung mass acceleration, suspension working space at front and rear corresponding to the MR damper suspensions and the active suspensions. This is also formulated as a multi-objective optimization problem which is again solved by NSGA II. Results show that the MR damper suspensions perform better than passive suspension and active suspension with limited state feedback and close to full state feedback system with LQR control.

References

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