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TESTING OF CAR SUSPENSION WITH FAST MR DAMPER CONTROLLED BY MODIFIED GROUNDHOOK ALGORITHM

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Abstract: *The paper describes a comparison of traditional passive suspension to a suspension with MR damper controlled by on/off Modified groundhook algorithm. The MR damper used in an experimental trolley together with current controller has exceptionally short time response of force on control signal – up to 1.5 ms. The MR damper was mounted into experimental trolley, which is scaled quarter suspension car model. The experimental trolley was riding on a road simulator over a bump. The suspension quality was evaluated according to the standard deviation of sprung mass acceleration (the lower value means higher comfort) and according to the standard deviation of force (the lower value means better grip). The results show that suspension system controlled by Modified groundhook algorithm outperforms passive system, but the level of improvement is dependent on the setting of current respectively damping in on and off state.*

Keywords: Modified groundhook, fast MR damper, response time, tyre grip, comfort

1. Introduction

The possible wheel grip provided by suspension with passive dampers is limited. Many simulations proved that higher grip can be achieved when semiactive algorithms controlling the amount of dissipated energy are used (Poussot-vassal et al., 2012). These semiactive suspension systems can employ different types of controllable dampers. Valášek et al. (1998) used CDC damper for controlling the Truck suspension with Groundhook algorithm. Ahmadian et al. (2005) simulated semiactive suspension with magnetorheological damper.

Simulations, however, often use idealized models of dampers with zero time response. In real situations, the time response of MR damper can be in tens of milliseconds (Koo et al., 2006). Eslaminasab and Golnaraghi (2008) showed the significant influence of the damper time response on semiactive suspension performance on 1 DOF system. Strecker et al. (2015) implemented time response of a MR damper into the quarter model of car suspension. Results from simulations showed that suspension controlled by Groundhook algorithm cannot offer better wheel grip when MR damper with long time response is used. Experiment confirmed no improvement in tyre grip when automotive MR damper with response time 8 ms was used in experimental trolley. The improvement in grip, predicted by the simulations with MR damper with response time 2 ms, was not experimentally evaluated, because it was not possible to obtain MR damper with such low response time.

Reasons of long response time of MR devices were described in Maas and Güth (2011). They also designed a MR clutch with very short time response. Based on this knowledge, Strecker et al. (2015) designed a fast MR damper, with time response of damper force on control signal up to 1.5 ms. Such time response can be reached only in case when fast current controller with voltage overdrive is used.

The MR damper with fast time response was never experimentally evaluated in car suspension. This paper describes the performance of such damper in semiactive suspension in comparison with passive damper.

2. Methods

The experimental setup is in Fig. 1:

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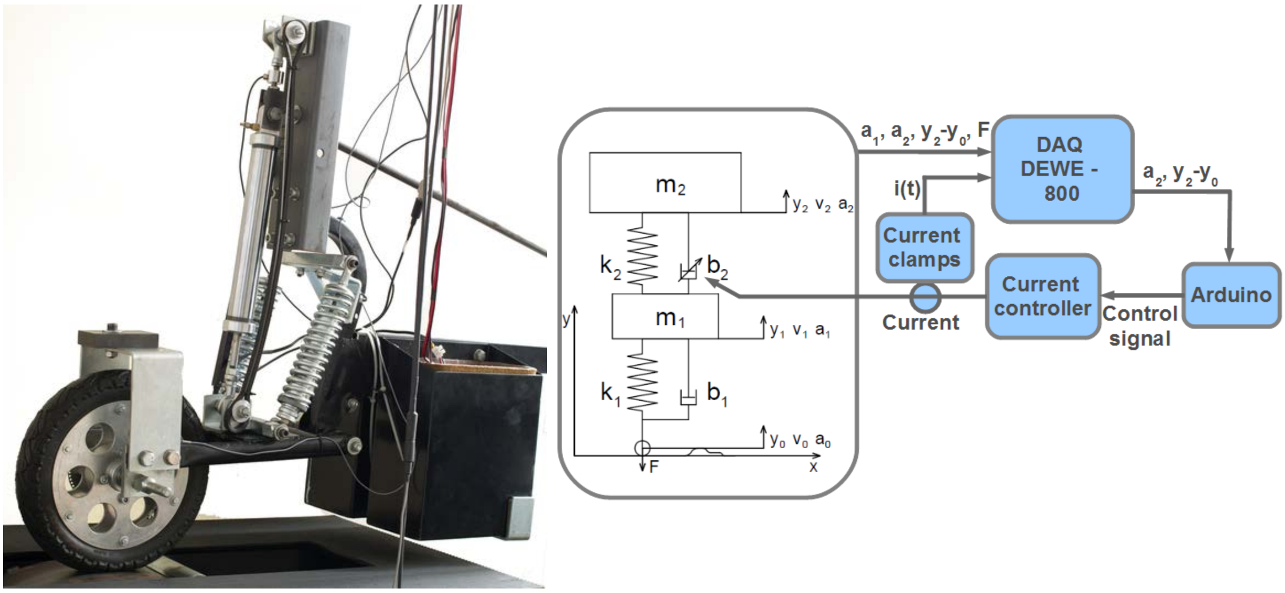

Fig. 1: The experimental trolley (left) and the block scheme of experimental setup

The experiment was conducted on a quarter car suspension model (Fig. 1) with unsprung mass m_1, sprung mass m_2, tyre stiffness k_1, main spring stiffness k_2, damping of the tyre b_1 and damper with variable damping b_2. The damping is dependent on piston velocity and electric current in the MR damper coil (Fig. 2). The other parameters are in Tab. 1. The experimental trolley was riding on the road simulator with the velocity 10 km/h over speed bump with the length 55 mm and height 21 mm.

Tab. 1: The parameters of experimental trolley

Dynamic tyre stiffness k_1 [N/mm]	50,2
Sprung mass m_2 [kg]	42.2
Unsprung mass m_1 [kg]	6.7
Overall stiffness k_2 [N/mm]	7,4

The measured force-velocity dependency for the currents between 0-2 A is in Fig. 2:

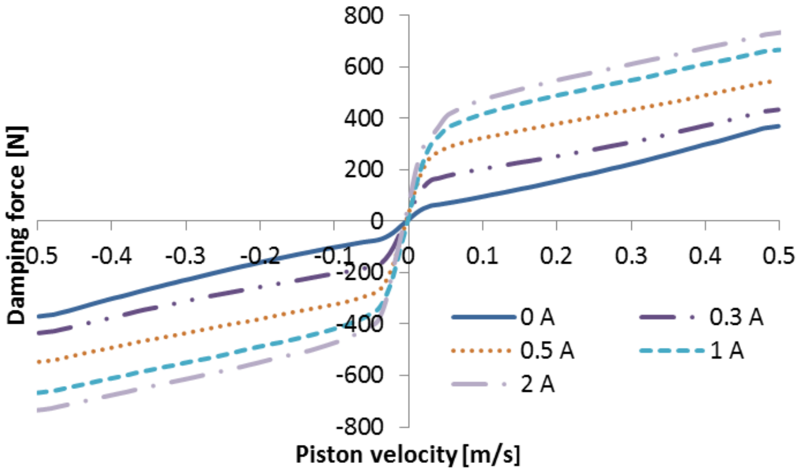

Fig. 2: F-v dependency of MR damper

The suspension quality was evaluated according to the standard deviation of sprung mass acceleration (1) which reflects comfort (the lower sprung mass acceleration standard deviation means better quality) and standard deviation of force on the road *F* (2) which reflects the tyre grip (the lower value means better grip), where F_{stat} is static force on the road:

$$\sigma(a_2) = \sqrt{\frac{1}{N}\sum_{i=1}^{N} a_{2(i)}^2} \tag{1}$$

$$\sigma(F) = \sqrt{\frac{1}{N}\sum_{i=1}^{N} (F_i - F_{stat})^2} \tag{2}$$

The suspension quality was evaluated for the whole range of the possible passive settings and for Modified groundhook algorithm. In this settings, the electric current to the coil was switched between two states – with low current I_L (low damping) and high current I_H (high damping). The rule for switching between these two states was according to the unsprung mass acceleration a_1, and relative velocity of sprung and unsprung mass v_2 - v_1 (3).

$$\begin{aligned} a_1(v_2 - v_1) \geq 0 \Rightarrow I = I_H \\ a_1(v_2 - v_1) < 0 \Rightarrow I = I_L \end{aligned} \tag{3}$$

The signals with acceleration of sprung mass, unsprung mass, relative displacement and force of the wheel to the road were sampled at 5 kHz and recorded by DEWE-800 measurement station. The signals with relative displacement and acceleration of unsprung mass were also used as input for control loop programmed in Arduino Due board (Fig. 2 right). The control loop was counting an output signal corresponding to the electric current I according to the equation (3). The relative velocity of sprung and unsprung mass was calculated from the rate relative displacement divided by control loop period. The signal with relative velocity was filtered by low-pass IIR filter with the cutoff frequency 360 Hz.

3. Results and discussion

The results are in Fig. 3. The passive setting for the current 0 A exhibits the best comfort, but the grip is the worst. With the rising current up to 0.5 A, the grip is improving, but the comfort is getting worse. The use of currents higher than 0.5 A does not bring any advantage, because both grip and comfort are getting worse.

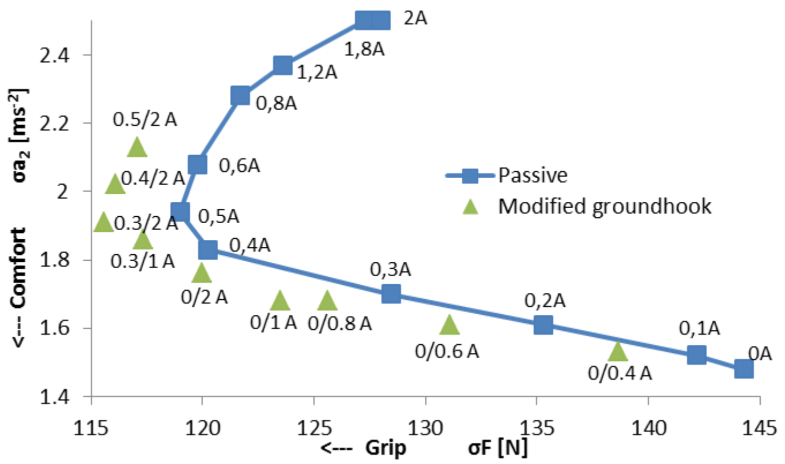

Fig. 3: Comparison of passive and modified groundhook controlled suspension

Suspension controlled by Modified groundhook algorithm exhibits better performance than passive suspension for all settings. When the current for low damping I_L was 0 A, the comfort of suspension was better than for passive settings with the same level of the grip. For achieving better grip than any passive setting, it was necessary to increase I_L. The best grip was reached for $I_L = 0.3\,A$ and $I_H = 2\,A$.

Fig. 4 shows the courses of unsprung mass acceleration and filtered relative velocity together with ideal desired current and the real current. It can be seen that the course of real current is delayed in comparison with desired current and especially for small amplitudes of relative velocity, the current is switched not exactly according to the algorithm. These differences are probably caused by delay from IIR low pass filter used for relative velocity and the noise in the signal.

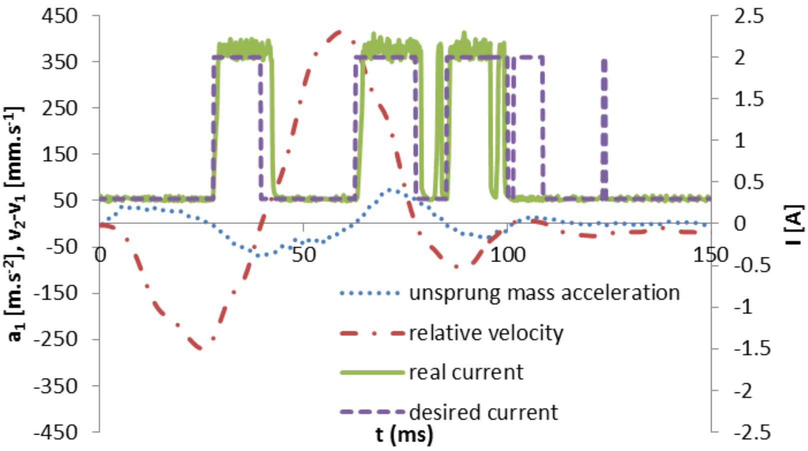

Fig. 4: The courses of current switching

4. Conclusions

The results from measurement showed that semiactive suspension with fast MR damper controlled by Modified groundhook algorithm is able to outperform any passive setting especially in tyre grip. The suspension performance is however sensitive on setting of the currents I_H and I_L. The measurement was conducted only for one type of bump with relatively high amplitudes of unsprung mass acceleration and relative velocity amplitudes. The switching of the current to the MR damper for small amplitudes was not exactly according to the algorithm. For smoother roads with smaller wheel disturbances, it will be necessary to use sensors with higher sensitivity and lower noise.

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References

Ahmadian, M., Goncalves, F.D. & Sandu, C. (2005) An experimental analysis of suitability of various semiactive control methods for magneto rheological vehicle suspensions, in: Smart Structures and Materials 2005: Damping and Isolation, pp. 208–216

Eslaminasab, N. & Golnaraghi, M.F. (2008) The effect of time delay of the semi-active dampers on the performance of on-off control schemes, in: Proceedings of the Asme International Mechanical Enginering Congress and Exposition 2007, Vol 9, Pts a-C, pp. 1911–1918.

Koo, J.-H., Goncalves, F.D. & Ahmadian, M. (2006) A comprehensive analysis of the response time of MR dampers. Smart Materials and Structures, 15,2, pp. 351–358.

Maas, J. & Güth, D. (2011) Experimental Investigation of the Transient Behavior of MR Fluids, in: ASME 2011 Conference on Smart Materials, Adaptive Structures and Intelligent Systems, Scottsdale, pp. 228-239.

Poussot-vassal, C., Spelta, C., Sename, O., Sergio, S. & Dugard, L. (2012) Survey and performance evaluation on some automotive semi-active suspension control methods : A comparative study on a single-corner model, Annual Rewievs in Control, 36, 1, pp. 148-160.

Strecker, Z., Roupec, J., Mazůrek, I., Machacek, O., Kubík, M. & Klapka, M. (2015) Design of magnetorheological damper with short time response, Journal of Intelligent Material Systems and Structures, 26, 14, pp. 1951–1958.

Strecker, Z., Mazůrek, I., Roupec, J. & Klapka, M. (2015) Influence of MR damper response time on semiactive suspension control efficiency, Meccanica, 50, 8, pp. 1949–1959.

Valášek, M., Kortüm, W., Šika, Z., Magdolen, L. & Vaculín, O. (1998) Development of semi-active road-friendly truck suspensions Control Engineering Practice, Elsevier 6, 6, pp. 735–744.