20th International Conference
ENGINEERING MECHANICS 2014
Svratka, Czech Republic, 12 – 15 May 2014

EXPERIMENTAL EVALUATION OF MR DAMPER TIME RESPONSE ON MODIFIED GROUNDHOOK ALGORITHM EFFICIENCY

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Abstract: *Semiactive algorithms have great potential in improving car suspension. One of the damper types with adjustable characteristics, which seems to be suitable for semi-active car suspension, is the magnetorheological damper. Such control algorithms require the ability to switch damping characteristics within one stroke. Time response of car MR dampers is in the range of tens of milliseconds. Although the time response is often ignored in semiactive algorithm simulations, it can influence the suspension efficiency in real systems. The influence of MR damper time response on the modified groundhook algorithm was simulated on quarter-car suspension model and verified on an experimental trolley. Results show that ignoring time response of MR damper during design of the semiactive suspension can reduce overall suspension quality of a real system.*

Keywords: MR damper, Modified groundhook, Response time, Suspension, Semi-active.

1. Introduction

The aim of the car suspension is minimization of sprung mass vibrations (comfort function) and ensuring as stable grip as possible (safety function). Recently, only passive systems have been used in most of the cases. Better suspension quality can be achieved when a fast semi-active suspension system is used. In this case, the damper characteristic is changed several times within one stroke.

Many semiactive control algorithms have been designed in theory. These algorithms can be generally divided into two groups. The First group consists of algorithms improving ride comfort. This group includes the skyhook algorithm which was originally designed by Karnopp et al. (1974) and further optimized by Ahmadian et al. (2005). The Second group consists of algorithms improving wheel grip. The most famous algorithm belonging to this group – groundhook was described by Valášek et al. (1998). Yao et al. (2002), Koo et al. (2004) and Kim et al. (2007) compared suspension quality with MR dampers using semiactive algorithms and showed their considerable potential. Authors, however, ignored time response of the MR damper (time needed for reaching 63% of final steady-state value after a step of the control signal).

Maas et al. (2011) designed a MR clutch with very fast time response. The time response (dependent on ferrite particles to oil ratio in the MR fluid) was measured in the range of 0.76 – 1.26 ms. Goncalves et al. (2006) measured time response of the MR fluid itself. Again, the time response was dependent on ferrite particles to oil ratio and was in the range of 0.45 – 0.6 ms. Although authors Koo et al. (2006) and Yang et al. (2004) measured time responses of usual MR dampers in the range of tens of milliseconds, time response shorter than 1.5 ms can be expected from MR damper if designing methods from fast MR clutch construction are used.

2. Materials and Methods

The impact of time response on semiactive algorithm efficiency was tested on a quarter car suspension model (Fig. 1), where MR damper is used. Its damping characteristics can be changed by the current in the coil.

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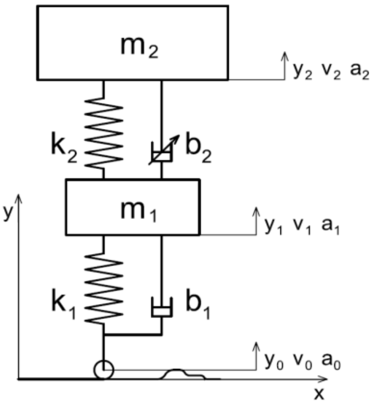


Fig. 1: Quarter suspension model used for simulation.

2.1. Algorithm principle

For evaluation, an algorithm which improves grip was chosen. The groundhook algorithm however needs, as one of the input signals, relative speed of the wheel to the road. This signal is very difficult to obtain in real conditions. Therefore, modified groundhook algorithm was designed. This algorithm needs only unsprung mass acceleration and relative velocity of sprung and unsprung mass signals. The rule for switching the damper to high damping state b_{2h}, respectively low damping state b_{2l}, is according to equation (1):

$$\begin{aligned} a_1 \cdot (v_2 - v_1) \geq 0 \Rightarrow F_{GHMOD} = b_{2h} \cdot (v_2 - v_1) \\ a_1 \cdot (v_2 - v_1) < 0 \Rightarrow F_{GHMOD} = b_{2l} \cdot (v_2 - v_1) \end{aligned} \tag{1}$$

2.2. Experiment

The suspension quality was measured on a Pioneer experimental trolley which was riding over a speed bump on a Dynotec road simulator (Fig. 2). Modal parameters of the trolley were tuned to the similar characteristics like rear suspension of Škoda Fabia car. Two options were compared – passive setting of the MR damper and damper controlled with semiactive algorithm modified groundhook. The control range of the MR damper was chosen in order to reach best possible comfort and best possible grip in passive mode. It was possible to change the response time in the range of 8.4 – 22 ms. On the trolley, there was an unsprung mass acceleration sensor, stroke position sensor (needed for algorithm) and sprung mass acceleration sensor (used for suspension quality evaluation). The road simulator was equipped with a sensor measuring force of the wheel on the road (used for suspension quality evaluation) and with a hall sensor for measuring the speed of the road.

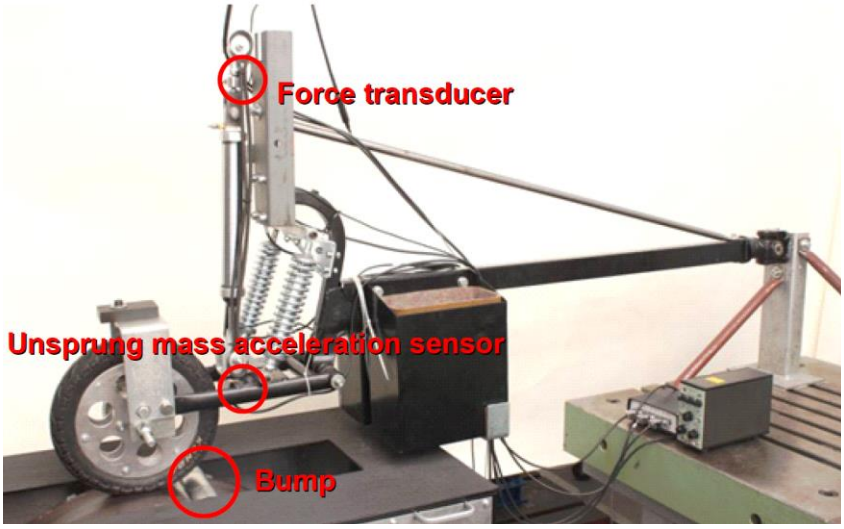


Fig. 2: Experimental trolley on the road simulator.

The suspension quality was evaluated with the help of deviation of the sprung mass acceleration – eq. (2) (the lower value, the better comfort) and deviation of wheel on the road force – eq. (3) (the lower value, the better grip):

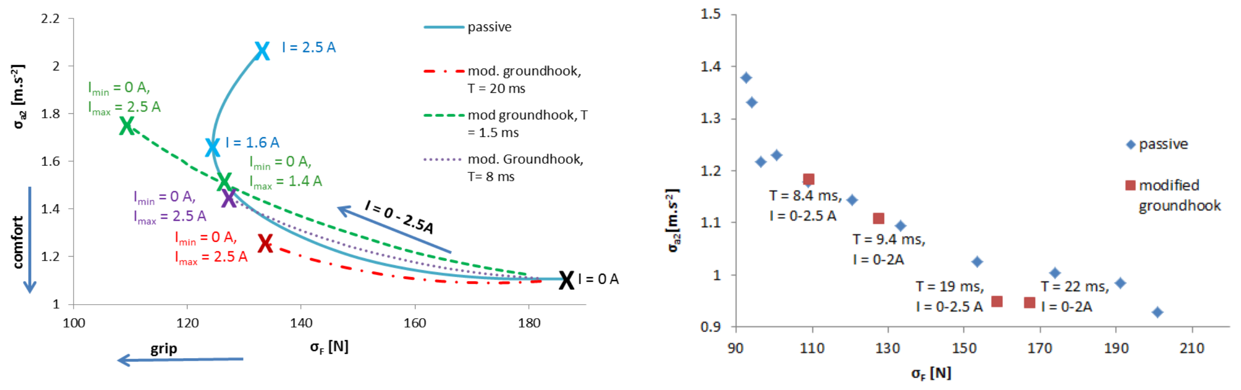
$$\sigma(a_2) = \sqrt{\frac{1}{N}\sum_{i=1}^{N} a_{2i}^2}\ , \tag{2}$$

$$\sigma_F = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(F_i - F_{stat})^2} \tag{3}$$

3. Results

In Fig.3 the suspension quality in passive mode is compared to suspension quality using semiactive algorithm modified groundhook. Solid line shows dependency of grip and comfort on electrical current (damping respectively) of the suspension in passive mode. The best comfort was achieved for zero current, but the grip was the worst. With growing current (higher damping) the comfort drops, but the grip grows. When the current is 1.6 A, the best possible grip is reached and further current grow (higher damping) causes decrease of both grip and comfort.

Dash-dot line shows the result of suspension controlled with modified groundhook algorithm with MR damper with usual response time (20 ms), dotted line is for MR damper with 8 ms (shortest possible for used MR damper) and dashed line is for MR damper with very short response time (1.5 ms). When the suspension is in semiactive mode, MR damper can be switched into two states – with high current I_{max} (large damping) and with low (or without) current I_{min} (small damping). In the modified groundhook mode with MR damper response time 1.5 ms, a current smaller than 1.4 A is not expedient, because in comparison with passive mode, both comfort and grip are worse. When the damper is switched between states with 0 A and 2.5 A, much higher grip can be achieved in comparison with any setting in passive mode. This applies, however, only for suspension with MR damper with short response time. When the response time is 20 ms, comfort is slightly improved, but it is impossible to reach higher grip in comparison with passive mode even when the largest possible range of the damper is used.



a) *b)*

Fig. 3: Comparison of suspension quality in passive and semi-active mode:
a) Simulation; b) Experiment.

In Fig. 3b there are experimental results with suspension in passive and "slow" semiactive mode. Measurements show that when the response time of the MR damper was between 19 - 22 ms, comfort was slightly improved. When the MR damper response time was reduced to 8.4 - 9.4 ms, no improvement compared to passive mode was achieved (in accordance with simulation). It can be assumed that suspension quality of a real system can be improved by using modified groundhook algorithm only in case when the response time of the damper is < 1.5 ms.

The explanation is in Fig. 4. When the response time of the damper is 20 ms, the violet line shows the force growth, respectively drop, after switching the electrical current on and off.

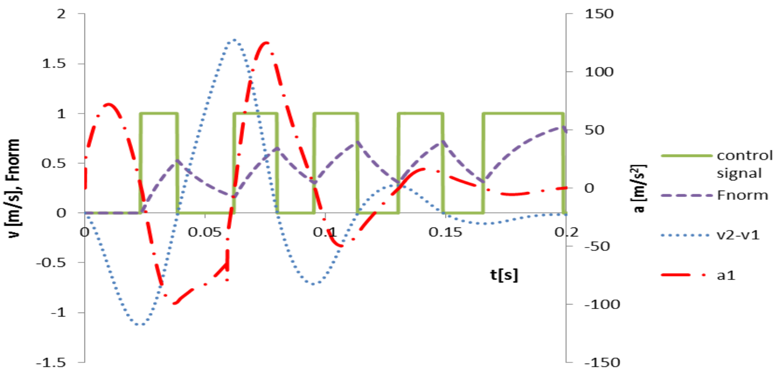


Fig. 4: Time course of generated force of MR damper with 20 ms time response.

4. Conclusions

New semiactive algorithm - modified groundhook was designed. This algorithm can in comparison with passive suspension improve grip, but it does not need the signal with relative speed between the wheel and road like conventional groundhook. Simulations show that if the response time of the MR damper is long, the quality of suspension controlled with modified groundhook algorithm can not bring improvement to passive mode. The results from simulations were confirmed by measurements with MR damper with time response 8 ms and 20 ms. Significant improvement of the grip is expected in case when the MR damper with time response < 1.5 ms is used in semiactive suspension. These conclusions are however based only on the results from simulations. Experimental verification was not conducted, while a MR damper with such short response time is not available. Considering existence of MR devices with time < 1.5 ms, possibility of development of MR damper with short response time is high. At the same time it is necessary to change significantly the conventional construction of MR dampers.

Acknowledgements

This work is an output of cooperation between GAČR13-31834P, FSI-S-14-2329and NETME Centre, regional R&D centre built with the financial support from the Operational Programme Research and Development for Innovations within the project NETME Centre (New Technologies for Mechanical Engineering), Reg. No. CZ.1.05/2.1.00/01.0002 and, in the follow-up sustainability stage, supported through NETME CENTRE PLUS (LO1202) by financial means from the Ministry of Education, Youth and Sports under the "National Sustainability Programme I".

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