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A NEW METHOD OF MAGNETORHEOLOGICAL DAMPER QUALITY EVALUATION

O. Macháček*, M. Kubík, P. Novák

Abstract: *The paper describes the comparison of magnetorheological dampers controlled by semi-active algorithm with different parameters in one suspension system. Response time, dynamic range and damping in activated state are the most important parameters of MR damper. Without any analysis it is extremely difficult to determine the best setting of these parameters. The analysis mentioned in this study compares acceleration transmissibility of system with different damper parameters. This comparison is based on conversion of transfer function into the newly defined single value - transfer coefficient. The more suitable parameters of MR damper, the lower transfer coefficient is exhibited by the suspension system. The analysis also shows that the high-efficient MR damper should have response time as short as possible. Furthermore, it could be inefficient or even counterproductive to achieve the highest dynamic range for each value of damping in activated state. The method of MR damper quality evaluation helps to define the best parameters of MR damper for the specific suspension system where the damper is going to apply.*

Keywords: MR damper, Semi-active, Adaptive, Acceleration transmissibility, Transfer coefficient.

1. Introduction

Magnetorheological (MR) dampers can change damping due to magnetorheological effect described by Winslow (1949). In adaptive mode, the most important parameters are damping forces in activated and inactivated state, Yang (2002) referred the ratio between them as dynamic range. There are several ways how to improve the dynamic range, for example by friction elimination mentioned in our previous study, Macháček (2016).

Besides, the damping in activated state and dynamic range, in semi-active mode there is another essential parameter – response time. This fact was confirmed by Eslaminasab (2008) for semi-active suspension performance on 1 DOF system, or by Strecker (2015) for the quarter model of car suspension.

The response time of MR damper is an interval necessary to change the damping force. The measurement published by Strecker (2015) confirm, that the damping force increase or decreases exponentially, when the control signal is much faster than the response time of MR damper. Therefore, it is hard to detect exactly finish of force increase or decrease. For that reason the response time of MR damper is defined as a period necessary for change from *0 %* to *63.2 %* or from *100 %* to *36.8 %* of damping force, see Goncalves (2002).

There are many algorithms of semi-active control which improve efficiency of MR damper compared with the adaptive mode, see Liu (2005). Liu compared several algorithms by acceleration transmissibility. This curve can be also called transfer function but only for linear systems. The lower the transfer the more suitable algorithm for vibration elimination of sprung mass.

The aim of this work is to evaluate the impact of different adjustment of MR damper to the specific semi-active suspension system behaviour. And define a combination of the parameters (time response, dynamic range and damping in activated state) which exhibits the lowest transfer of vibration.

* All authors: Institute of Machine and Industrial Design, Brno University of Technology, Technická 2896/2, 616 69 Brno; CZ, Ing. Ondřej Macháček: Ondrej.Machacek@vutbr.cz

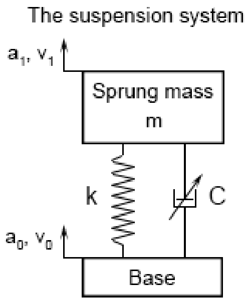
2. Methods

A chosen suspension system was created in multi-body software ADAMS view 2012, the system is described in chapter 2.1. Moreover, a new method of MR damper quality evaluation in respect of sprung mass vibration elimination. The method is described in chapter 2.2. It is based on the acceleration transmissibility comparison using a newly defined single value - transfer coefficient.

2.1. Model of suspension system

A simple suspension system with one degree of freedom has been chosen, see Fig. 1. It consists of two rigid bodies, the first one - base is cinematically excited by acceleration a_0 in vertical direction. The excitation respects sweep sine function in frequency range *0 – 100 Hz* and amplitude $a_{0max} = 9.81\ m \cdot s^{-2}$. The second one: sprung mass, has mass $m = 100\ kg$, it is linked in vertical direction and the response of acceleration a_1 can be observed there. There is spring and damper between the sprung mass and the base. The stiffness of the spring is $k = 395\,000\ N \cdot m^{-1}$, so the natural frequency of the suspension system is $f_n = 10\ Hz$ and critical damping $Cc = 12\,570\ N \cdot s \cdot m^{-1}$. The sampling frequency used for the simulations was $fs = 4\ kHz$.

The damper in model is considered as a magnetorheological, therefore the damping C is adjustable. The ON/OFF skyhook algorithm was used for semi-active mode in this study. The algorithm control the damping according to equations (1 – 2), shown in described by Liu (2005):



$$v_1 \cdot (v_1 - v_0) \leq 0 \qquad C = C_{ON} \qquad (1)$$

$$v_1 \cdot (v_1 - v_0) > 0 \qquad C = C_{OFF} \qquad (2)$$

$$C_{OFF} = \frac{C_{ON}}{D} \qquad (3)$$

Fig. 1: The suspension system and equations of control algorithm ON/OFF Skyhook.

Where v_1 is velocity of the sprung mass and v_0 is velocity of the base. Both variables are monitored in the direction of excitation (vertical).

The damping of the MR damper in activated state C_{ON} was set between $0.2 \cdot C_c$ and $1 \cdot C_c$ in this article. The damping is considered linear, therefore the damping in inactivated state C_{OFF} can be defined by dynamic range using equation (3).

Ideally, the skyhook algorithm uses zero as C_{OFF}, thus the dynamic rang has to be infinitely high $D = inf$. This impossible scope was taken into account only for comparison with other feasible dynamic ranges $D = 2; 5; 7; 10$.

Infinitely short response time $t_{re} = 0\ ms$ is another idealization which is often used in simulations of MR. However, it was also used in this study for comparison with other response times $t_{re} = 1\ ms; 2\ ms; 5\ ms; 10\ ms$.

2.2. Transfer coefficient

Frequency response of sprung mass acceleration a_1 and frequency response of excitation (base acceleration) a_0 were used for the acceleration transmissibility T calculation. Both frequency responses were converted into frequency domain using FFT with the same parameters. The fraction was counted separately for each the frequency component:

$$T(f) = \frac{a_1(f)}{a_0(f)} \qquad (4)$$

A newly defined variable for the MR damper quality evaluation, transfer coefficient T_c, is defined as a sum of power spectral density of the suspension system acceleration transmissibility.

$$T_c = \int_{f_{min}}^{f_{max}} T(f)^2 \cdot df \qquad (5)$$

Frequency range of the sum was chosen with respect to the excitation from f_{min} = *0 Hz* to f_{max} = *100 Hz*.

3. Results and discussion

Many simulations with parameters described previously were provided. The results of these simulations help to answer the questions. The first one about response time was tested for several different damping. The results showed, as expected, that the shorter response time the lower transfer coefficient was in all configurations. However, only one damping in activated state ($C_{on}= 1 \cdot Cc$) is presented in Fig. 2. There is the transfer coefficient – dynamic range dependency on the left of the figure. The acceleration transmissibility curves which was used for transfer coefficient calculation for the dynamic range $D = 10$ (marked by triangles) are shown on the right of the Fig. 2.

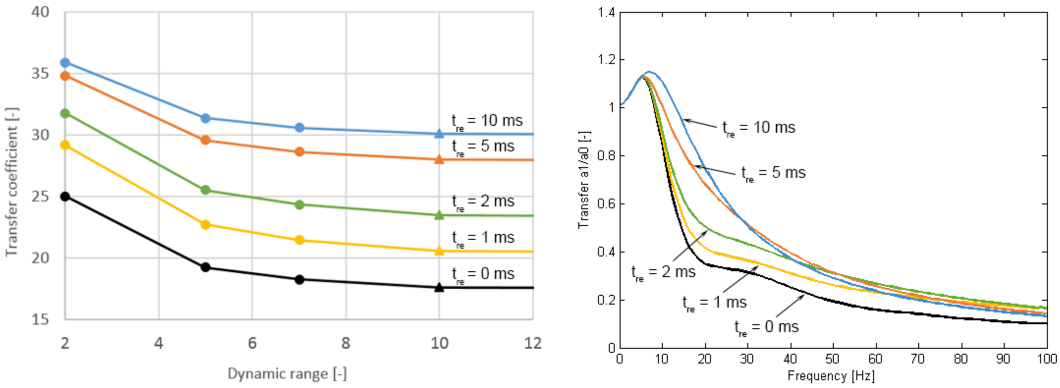


Fig. 2: The MR damper response time influence to the transfer coefficient for Con = 1·Cc and different dynamic range (left) for Con = 1·Cc and D = 10 (right).

The most appropriate adjusting of MR damper depends on the dynamic range. When the dynamic range is $D = 1$, the MR damper works with constant damping. The system with low damping exhibits higher transfer near natural frequency than highly damped system. However the lower damping of the system cases lower transfer for higher frequencies than highly damped system, see Fig. 3-left.

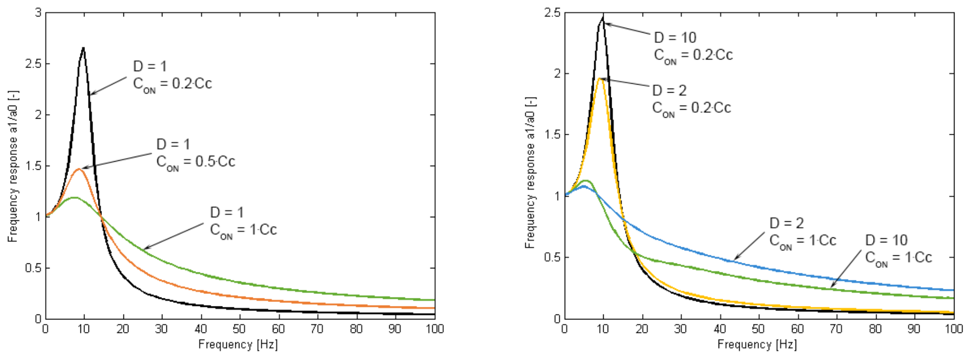


Fig. 3: The acceleration transmissibility curves for different adjusting of MR damper with constant damping (left) and for semi-active damper (right).

The same phenomenon can be observed in semi-active mode (when the dynamic range $D > 1$), but effect of the phenomenon is not the same for all configurations of the system. Dynamic range increasing for $C_{ON} = 0.2 \cdot Cc$ significantly increases the transfer near natural frequency while, decreasing of transfer for high frequencies is marginally. Otherwise, dynamic range increasing for $C_{ON} = 1 \cdot Cc$ insignificantly increase the transfer near natural frequency while, decreasing of transfer for high frequencies is significant. Thus, increasing of dynamic range can be considered as positive for high damped system, and negative for low damped system with semi-active damper.

This feature affects the results of transfer coefficient calculation. Therefore, it is possible to find minimum of transfer coefficient for each dynamic range of MR damper, which is marked by square in Fig. 4. This minimum can be considered as the best adjustment of C_{ON}.

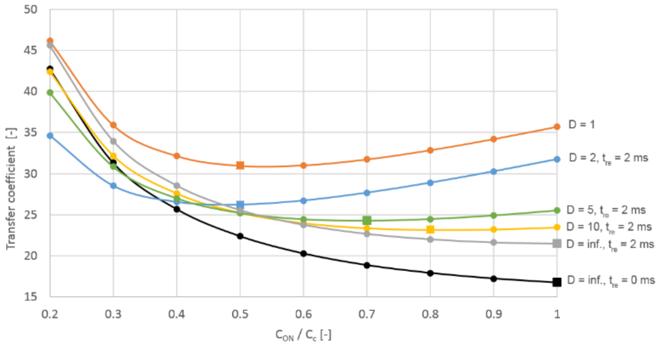


Fig. 4: The transfer coefficients for different adjusting of MR damper parameters.

4. Conclusions

This paper presents a new method of efficiency evaluation of MR damper in a suspension system using comparison of acceleration transmissibility curves, due to conversion the curve into single value – transfer coefficient. Calculation of the transfer coefficient is based on sum of power spectral density of suspension system acceleration transmissibility. The results showed that for MR damper with short time response and high dynamic range, it is beneficial to increase the damping in activated state.

Application of described methodology shows that the shorter response time of MR damper the better. Moreover, when the response time of semi-active damper is higher than *10 ms*, the transfer coefficient is higher than the lowest transfer coefficient achieved by MR damper with constant damping. Significant decrease of transfer coefficient was achieved with response time *2 ms* or lower.

The higher dynamic range the lower transfer coefficient is valid only for $C_{ON} > 0.5\ C_c$. MR damper with very high dynamic can be advantageously used in the suspension system with damping in activated state near to critical. But, the differences between the transfer coefficient for *D=inf* and $D = 10$ are minimal. Therefore, the dynamic range $D = 10$ can be considered as suitable for the suspension system described in this study. The optimal damping of the MR damper in activated state for this dynamic range is $C_{ON} = 0.8\ Cc$. When the ON/OFF skyhook was used for control of MR damper with these parameters, the transfer coefficient is reduced by 25 %, compared with the best adjustment of damper with constant damping.

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