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# SEMIACTIVE SEAT SUSPENSION FOR AGRICULTURAL MACHINES

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**Abstract:** *This paper deals with the simulation of a seat suspension with a magnetorheological (MR) damper for agricultural machines. The dynamic model of the seat is a single degree of freedom model with non-linear damping characteristics and response time of the damper. In the model, three control algorithms were implemented – two-state Skyhook, Skyhook linear approximation damper control, and Acceleration Driven Damper control. The excitation signal for the model was a real record of acceleration measured on the frame of the tractor. The suspension quality was compared using a standard deviation of acceleration. Results have proven significant improvement in suspension quality when any of the three mentioned algorithms was used.*

**Keywords: Driver seat, Rresponse time, Semiactive suspension, Magnetorheological damper, Skyhook.**

## 1. Introduction

In tractors and agricultural machines, a human body is exposed to vibrations transmitted from the frame of the vehicle, which leads to increasing driver's fatigue and reduced attention. To ensure maximum comfort, vibrations transmitted from the machine frame to the driver seat is required to be as low as possible. The requirements for damping are, however, opposed to high and low excitation frequencies. High damping ensures low resonance peak but causes high vibration transfer rate on high frequencies whereas low damping reduces vibration transfer on high frequencies but causes high seat amplitudes at resonance frequencies. The performance of a passive suspension system with a spring and a damper is therefore limited. Semiactive suspension systems with controllable damping force promise better vibroisolation. The damping force can be easily controlled with the magnetorheological (MR) dampers.

An important part of a designing system with an MR damper is to have a dynamic model that respects real parameters of the damper as a dynamic range and a response time. The response time of MR damper is defined as a time needed to reach 63.2 % of the final force. The paper of Strecker et al. (2019) describes the construction of the MR damper with response time up to 1.5 ms. Simulations of systems with MR damper were performed and comparisons of control algorithms were described in several studies (Poussot-Vassal et al., 2011; Koulocheris et al., 2017; McManus et al., 2002). In these articles, the response time of the damper is neglected and thus the results can be distorted. The authors of these articles used artificial signals such as sweep or road bumps as an excitation of the model. Due to the non-linear damping characteristics of the MR damper, it is important to know the amplitude of the vertical acceleration of the tractor frame. Therefore, it is preferable to excite the dynamic model with a real signal, which is measured on a tractor during work. Savaresi (2004) used measured signal for excitation of the model, but also neglected the response time of MR damper. Strecker et al. (2015) studied the influence of response time on reachable comfort and proved, that shorter response time has a positive influence on reachable comfort. Neglecting the real value of an MR damper response time in models gives better results than it is possible to reach on a real system. Therefore, for good correspondence between a model and a real set, it is necessary to implement response time into the model.

## 2. Methods

### 2.1. Dynamic model

The dynamic model of semiactive seat suspension was made in the program Matlab Simulink. The dynamic

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model is created as a model with one degree of freedom (see Fig. 1a). The force-velocity dependency of MR damper is non-linear (see Fig. 1b) with maximum dynamic range 10. The input signal to the model is the acceleration of the unsprung mass – frame of the tractor.

The main function of the seat suspension is to ensure the minimization of the vibrations transferred from the frame of the vehicle into the seat. The suspension quality was evaluated according to the standard deviation of seat acceleration defined by Eq. (1). The lower the value for given excitation, the better the suspension quality.

$$\sigma(a_1) = \left[\frac{1}{N}\sum_{i=1}^{N} a_{1(t)}^2\right]^{\frac{1}{2}} \tag{1}$$

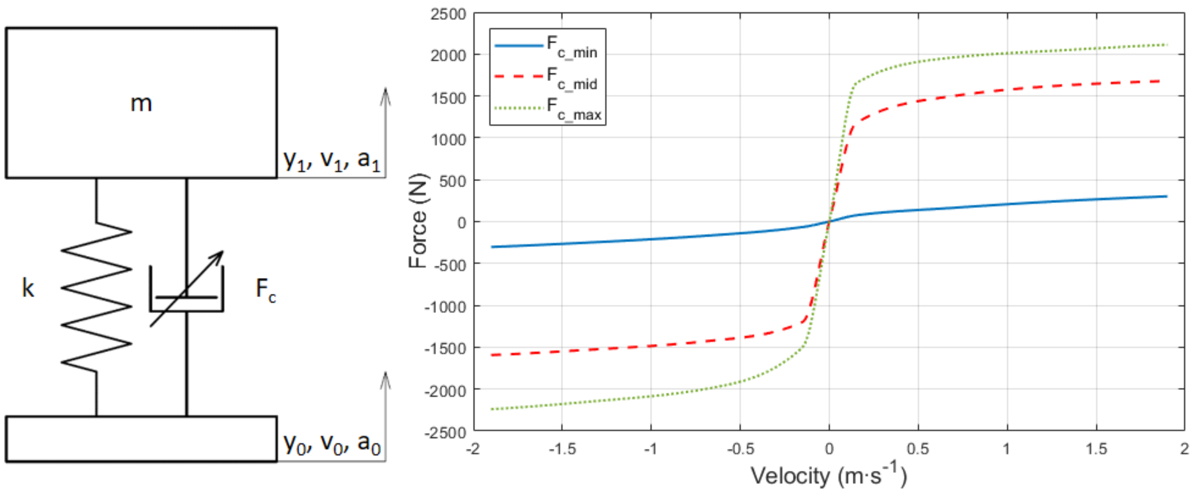


*Fig. 1: a) Model with one degree of freedom; b) F-v dependencies used in the model.*

### 2.2. Control algorithms

This section focuses on three algorithms, which are comfort-oriented and were implemented into the dynamic model.

#### Skyhook two-state damper control (SH-2)

The first implemented algorithm is the two-state Skyhook. This algorithm uses the velocity of sprung mass (seat) and the relative velocity between sprung and unsprung mass as input parameters. This algorithm switches between two damping characteristics for reaching optimal comfort. The control law is defined by Eq. (2).

$$F_c = \begin{cases} F_{c\_min}(v) & \text{if} \quad v_1 \cdot (v_1 - v_0) \leq 0 \\ F_{c\_mid}(v) & \text{if} \quad v_1 \cdot (v_1 - v_0) > 0 \end{cases} \tag{2}$$

#### Skyhook linear approximation damper control (SH-L)

This algorithm is an improved version of two-state Skyhook control, which can change the damping coefficient continuously and therefore needs continuously variable damper (e.g. the MR damper). The SH-L control law is given by (3).

$$F_c = \begin{cases} F_{c\_min}(v) & \text{if} \quad v_1 \cdot (v_1 - v_0) \leq 0 \\ sat\left(\frac{\alpha \cdot F_{c\_max}(v) \cdot (v_1 - v_0) + (1-\alpha) \cdot F_{c\_max}(v) \cdot v_1}{(v_1 - v_0)}\right) & \text{if} \quad v_1 \cdot (v_1 - v_0) > 0 \end{cases} \tag{3}$$

The function *sat()* (saturation operator) indicates the limits of the damping force $F_c$. The limits of the damping force are $F_c \in [F_{c\_min}\ F_{c\_max}]$. Parameter $\alpha \in [0, 1]$ is the tuning parameter of algorithm SH-L. When $\alpha = 1$, this algorithm is equivalent to the SH-2 algorithm.

**Acceleration driven damper control (ADD)**

The ADD algorithm uses the control law similar to SH-2, but there is used the acceleration of sprung mass instead of the velocity. This algorithm is easier to implement because the acceleration is easier to measure than the velocity. The ADD control law is defined by (4).

$$F_c = \begin{cases} F_{c\_min}(v) & \text{if} \quad a_1 \cdot (v_1 - v_0) \leq 0 \\ F_{c\_max}(v) & \text{if} \quad a_1 \cdot (v_1 - v_0) > 0 \end{cases} \tag{4}$$

## 2.3. Measurement

The damping characteristic of the MR damper is non-linear and therefore the magnitude of the damping force is speed dependent. Hence, it is necessary to know the amplitude of the acceleration and the speed of a frame and the seat of the tractor that occur during work. For measurement of vibrations on a frame and a seat of the tractor, an inertial measurement unit (IMU) was used. The IMU consists of two separate boxes with accelerometers, where one measured acceleration on a frame, more precisely on a cab floor of the tractor and the second one measured the acceleration of the seat (see Fig. 2). Measurement results show that the acceleration of the cab floor is in the range between 3 ÷ 6 $m \cdot s^{-2}$ and acceleration of the driver seat is in the range between 1 ÷ 2.5 $m \cdot s^{-2}$ for a modern tractor with a suspended cab. For a tractor with a non-suspended cab, the amplitudes are approximately twice as high.

*Fig. 2: Measurement of vibrations in real conditions.*

## 2.4. Simulation results

The parameters of the simulations are: $m$ = 100 kg, $k$ = 9000 $N \cdot m^{-1}$. The excitation signal, obtained from a tractor John Deere 6110M, is 100 s long.

*Tab. 1: Results from simulations.*

| **Response time (ms)** | **Standard deviation of seat – acceleration ($m \cdot s^{-2}$)/position (mm)** | | |
|---|---|---|---|
| | **SH-2** | **SH-L (α = 0)** | **ADD** |
| 20 | 0.289/1.94 | 0.256/2.23 | 0.255/2.63 |
| 10 | 0.265/1.75 | 0.247/2.16 | 0.248/2.56 |
| 5 | 0.254/1.67 | 0.242/2.12 | 0.244/2.51 |
| 1.5 | 0.248/1.62 | 0.239/2.10 | 0.241/2.47 |
| Passive suspension | 0.339/2.81 | | |
| Excitation signal | 0.982/2.31 | | |

In Tab. 1 there is a comparison of the standard deviation of seat acceleration and position with different algorithms and different MR damper response times. All algorithms provide better vibration isolation when the short response time of the MR damper is used. Decreasing response time also causes a decrease in the seat position deviation.

In the Fig. 3 there is a comparison of position and acceleration of a seat, when the excitation signal is a road bump and the response time is 1.5 ms with all other parameters set to the same values as in previous simulations. The height of the bump was 100 mm, speed was 12 km·h$^{-1}$ and the bump was 600 mm long.

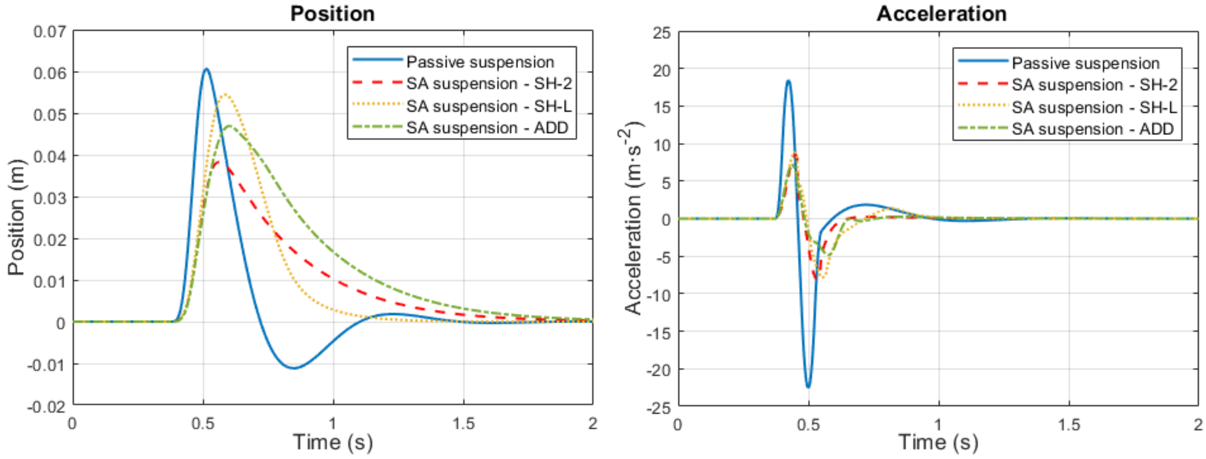


*Fig. 3: Comparison of algorithms.*

## 3. Conclusions

From simulations of the seat suspension system, a suitable form of F-v dependency was obtained. The simulations have proven that the response time influences reachable comfort – the fast response time increases reachable comfort. Results from the simulations with different algorithms show, that semiactive suspension provides better vibroisolation than passive suspension and reduces vibrations transferred from frame to the driver. The SH-L algorithm provides the best vibroisolation at any response time. The vibrations transmitted to the seat, when the response time of the MR damper 1.5 ms is used, are reduced 26.8 % for SH-2, 29.5 % for SH-L and 29.2 % for ADD algorithm in the comparison with the best passive suspension. Two-state Skyhook control causes lower position deviation of the seat than the other algorithms which is advantageous in terms of vehicle control. Due to the fact, that SH-2 and SH-L algorithms use the same input values, it is possible to change the control law easily. For the following experiments, it is suitable to use the SH-L algorithm because it ensures the best vibroisolation.

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