THE SEMI-ACTIVE GROUNDHOOK CONTROL OF SDOF SYSTEMS WITH HARMONICAL BASE EXCITATION

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The vibration level and the comfort of the vehicles can be improved by replacing its passive suspension by a controlled semi-active or active suspension. Various semi-active control algorithms have been suggested in the past, some of them are groundhook strategies. Many of these studies approach systems with more degrees of freedom. In this paper is presented the groundhook control strategy for SDOF dynamical system with harmonic base excitation in comparison with an undamped and linear damped dynamic system. The comparison is made by numerical simulation in Matlab Simulink for two important transfer functions of those dynamic systems. The results show that the semi-active control for sinusoidal excitation provides better results than the classic suspension.

Keywords: Semi-active, groundhook, sinusoidal excitation, SDOF system.

1. Introduction

Semi-active control systems were proposed early in the 1920s when patents were issued for shock absorbers which utilized an elastically supported mass to activate hydraulic valve (no power required) or utilized a solenoid valve for directing fluid flow (small amount of power required). For vehicles suspension control, the objective is to decrease the dynamic road-tyre forces in order to reduce the road damage. [1]

In many papers is shown that the groundhook control or extended groundhook control (which have the strong nonlinearity of the controlled shock absorber, especially its asymmetry) [2], can provide performance for dynamic system suspension. A passive suspension system has either low or high damping coefficient in function of desired comfort or stability characteristics. In the car suspension case, to isolate against random excitation, the damper needs to have both low and high damping coefficients almost in the same time. Therefore, the semi-active suspension design is a combination of these two goals [3].

Semi-active suspensions can achieve performance close to that of active suspensions with much lower cost and complexity [4]. The difference between

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active and semi-active suspensions is the use of active or semi-active damper in parallel with a passive spring.

In this paper is analyzed by numerical simulation, the effect of groundhook control to the behavior of SDOF dynamic systems with sinusoidal base excitation. The model used in this work was validated by comparing the results obtained by numerical simulation with the results obtained by the theoretical way in sinusoidal excitation case. The results show that the groundhook control can provide better performance than a simple suspension especially for higher dissipation coefficients.

2. Paper background

The schematic configuration of an SDOF dynamic system with semi-active groundhook control and base excitation proposed in this work is shown in Fig. 1.

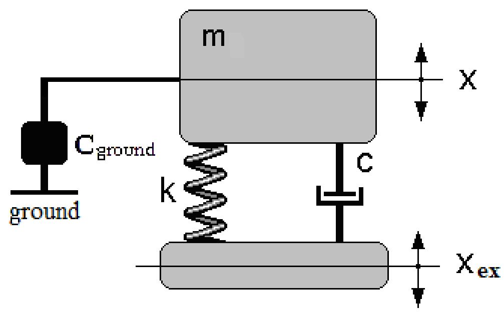

Fig. 1. The mechanical model of SDOF system with groundhook control and base excitation

The equation of motion of the uncontrolled SDOF model with base excitation is:

$$m\ddot{x} + c(\dot{x} - \dot{x}_{ex}) + k(x - x_{ex}) = 0 \tag{1}$$

The equation of motion of the entire model with linear dissipation and groundhook control is given by following relation:

$$m\ddot{x} + c(\dot{x} - \dot{x}_{ex}) + F_{ground} + k(x - x_{ex}) = 0 \tag{2}$$

Where the groundhook control function is given in literature by:

$$F_{ground} = \begin{cases} -G_{ground}\dot{x}_{un} & \dot{x}_{un}\left(\dot{x}_s - \dot{x}_{un}\right) < 0 \\ 0 & \dot{x}_{un}\left(\dot{x}_s - \dot{x}_{un}\right) \geq 0 \end{cases}, \tag{3}$$

where $\dot{x}_{un}$ is the velocity of the unsprung mass and $\dot{x}_s$ is the velocity of sprung mass.

The equation (3) can be written as:

$$\ddot{x} = -2\zeta\omega(\dot{x} - \dot{x}_{ex}) - f_{ground} - \omega^2(x - x_{ex}), \tag{4}$$

where we noted $f_{ground} = F_{ground} / m$.

In the literature, the relation (3) is given for the 2DOF systems with groundhook control, especially for car models [3]. For these models is clearly who the sprung mass and the unsprung mass are. The SDOF systems have just the sprung mass so is difficult to identify the correct strategy. Therefore, not one but three possible groundhook control functions were considered in this paper, but numerical simulations shows that just one of these tree strategies provides the best results:

a. The first function is a groundhook control associated with the velocity of the system excitation.

$$F_{ground-ex} = \begin{cases} -c_{ground}\dot{x}_{ex} & \dot{x}_{ex}\left(\dot{x} - \dot{x}_{ex}\right) < 0 \\ 0 & \dot{x}_{ex}\left(\dot{x} - \dot{x}_{ex}\right) \geq 0 \end{cases} \tag{5}$$

b. The second function is a groundhook control associate with the absolute velocity of the system mass.

$$F_{ground-abs} = \begin{cases} c_{ground}\dot{x} & , \dot{x}_{ex}\left(\dot{x} - \dot{x}_{ex}\right) \geq 0 \\ 0 & , \dot{x}_{ex}\left(\dot{x} - \dot{x}_{ex}\right) < 0 \end{cases} \tag{6}$$

c. The third function is a groundhook control associated with the relative velocity of the system mass.

$$F_{ground\_rel} = \begin{cases} c\left(\dot{x} - \dot{x}_{ex}\right), & \dot{x}\left(\dot{x} - \dot{x}_{ex}\right) \leq 0 \\ 0, & \dot{x}\left(\dot{x} - \dot{x}_{ex}\right) > 0 \end{cases} \tag{7}$$

Following numerical simulations we found that the only situation of groundhook control given by relation (6) provides better results in relation to uncontrolled linear suspension situation. Therefore this is the correct situation of SDOF system with sinusoidal base excitation and semi-active groundhook control. We can specify that the situation is different in the case of the SDOF systems with random excitation, in this situation groundhook control given by relation (5) and (7), provide as well, good results. The relation (6) can be written as:

$$f_{ground} = \zeta_{ground}\omega\dot{x}\left(1 + sign\left(\dot{x}_{ex}\left(\dot{x} - \dot{x}_{ex}\right)\right)\right) \tag{11}$$

Substituting in equation (4) the expressions of f_{ground} given by relationships (11) can be obtained the equations of motion of the dynamic system with semi-active groundhook strategy:

$$\ddot{x} = -2\zeta\omega(\dot{x} - \dot{x}_{ex}) - \omega^2(x - x_{ex}) - \zeta_{ground}\omega\dot{x}\left(1 + sign\left(\dot{x}_{ex}\left(\dot{x} - \dot{x}_{ex}\right)\right)\right) \quad (12)$$

In the literature, three important transfer functions are given, displacement (velocity, acceleration) transfer function, the transfer function between excitation displacement and response acceleration of the mass and the force transfer function, but just two of these were considered in this paper. For sinusoidal excitation these functions have the following expressions [5]:

a. The displacement (velocity, acceleration) transfer function:

$$F_T = \frac{X}{X_{ex}} = \frac{\dot{X}}{\dot{X}_{ex}} = \frac{\ddot{X}}{\ddot{X}_{ex}} = \sqrt{\frac{1+(2\zeta r)^2}{\left(1-r^2\right)^2 + (2\zeta r)^2}} \quad (13)$$

b. The force transfer function:

$$F_F = r^2\sqrt{\frac{1+(2\zeta r)^2}{\left(1-r^2\right)^2 + (2\zeta r)^2}} \quad (14)$$

where r = ω/ω_0 is the ratio between excitation frequency and proper frequency of the system.

To validate the dynamic model and the Matlab Simulink program for the charts obtained by using transfer functions relations (13-14), we compared the chart obtained by varying the excitation frequency and the relative damping coefficients, with the chart obtained by numerical simulations in the same condition for each transfer function. The results are almost the same as is shown in figs 2-3, which mean that the program and the theoretical approach are correct. [7]

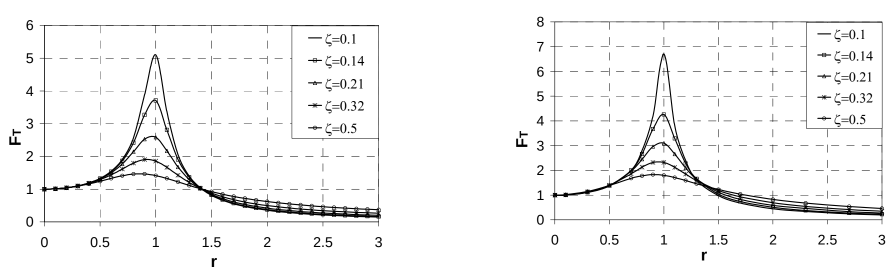

Fig. 2 Transfer function by theoretical way (left), by numerical simulation (right)

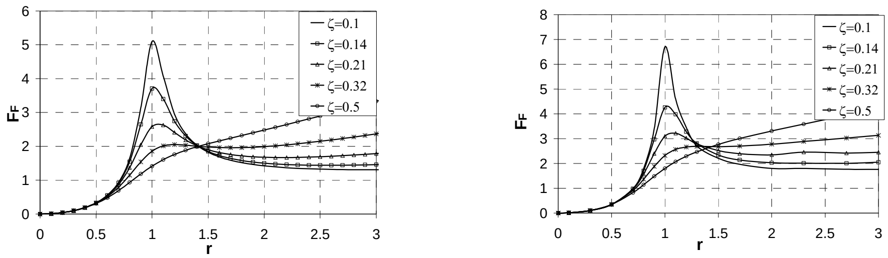

Fig. 3 Force transfer function by theoretical way (left), by numerical simulation (right)

3. Numerical simulation results

The simulation program has the following input parameters:

Table 1

Numerical simulation parameters

Natural frequency	f_o=1Hz
Excitation frequency	f=0.1…3 Hz
Linear relative dissipation coefficient	ζ=0…0.5
Groundhook relative dissipation coefficient	ζ_{ground}=0…0.3

In this paper is studied the response of the dynamic systems by using the method of comparison of the transfer functions (13-14) obtained by numerical simulation in three cases, undamped, linear damped, and semi-active groundhook control with harmonical base excitation. This approach is correct because in these three cases, the transfer functions are independent of excitation amplitude [6], as is shown in fig 4. For nonlinear systems, the approach by this method is not correct because these transfer functions depend to nonlinearity and the amplitude of excitation.

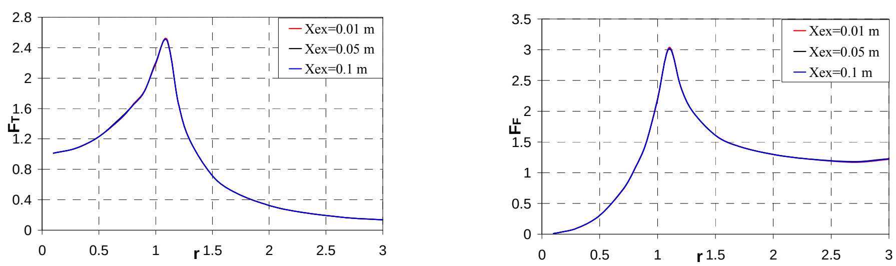

Fig. 4. The transfer functions for ζ_{ground}=0.3 and excitation amplitude X_{ex}=0.01, 0.05 and 0.1 m.

In fig. 5 are presented the displacement, the velocity and the acceleration of the mass in three cases, undamped, uncontrolled (linear damping) and groundhook controlled system in the sinusoidal base excitation case for f=1Hz (in resonance area). We chose the relative damping coefficients ζ and ζ_{ground} value 0.1

(not 0.3) for the excitation f = 1Hz (in the resonant area) to see the three curves in the same dimension, else undamped curve has much bigger amplitude in comparison with the others. In the legend we note z=ζ or ζ_{ground}. In this situation the uncontrolled and groundhook curves have almost the same amplitude.

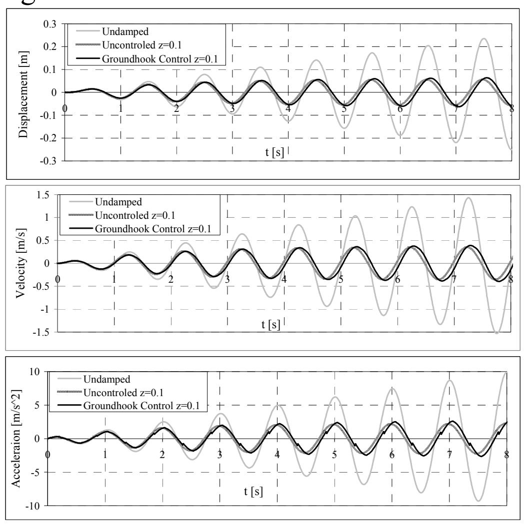

Fig. 5 Displacement, velocity and acceleration of the mass for excitation frequency f=1 Hz

In fig. 6 are presented the displacement, the velocity and the acceleration of the mass in three cases, undamped, uncontrolled (linear damping) and skyhook controlled system in the sinusoidal excitation case for f=3Hz (in isolation area). In this situation the undamped and groundhook curves are almost the same amplitude.

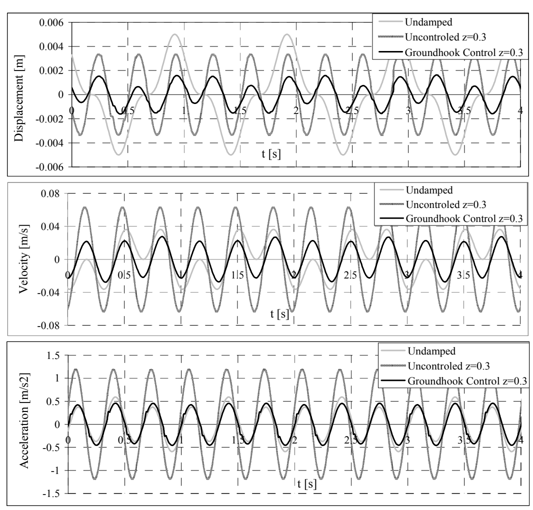

Fig. 6 Displacement, velocity and acceleration of the mass for excitation frequency f=3 Hz

In fig. 7 are presented the transfer functions for groundhook control ($\zeta_{ground}=0.3$) for some values of linear damping coefficient. The result shows that is better to use only semi-active strategy without suplimentar linear damping.

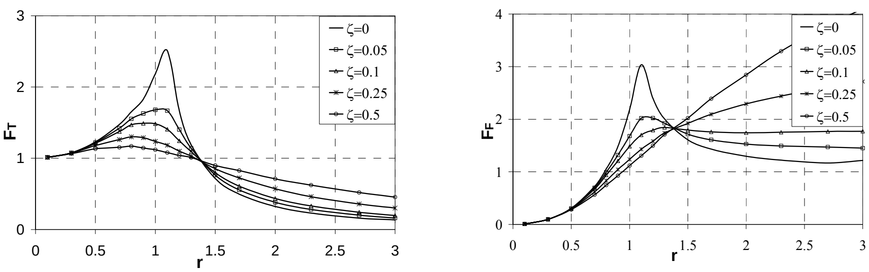

Fig. 7. Transfer function and force transfer function in groundhook control case $\zeta_{ground}=0.3$

In fig. 8 is shown the comparison between the transfer functions of SDOF systems with harmonic base excitation, in three cases, undamped, linear damped, and semi-active groundhook control. As is shown, the semi-active control with groundhook strategy of SDOF systems with harmonic base excitation can provide better performance than uncontrolled SDOF systems.

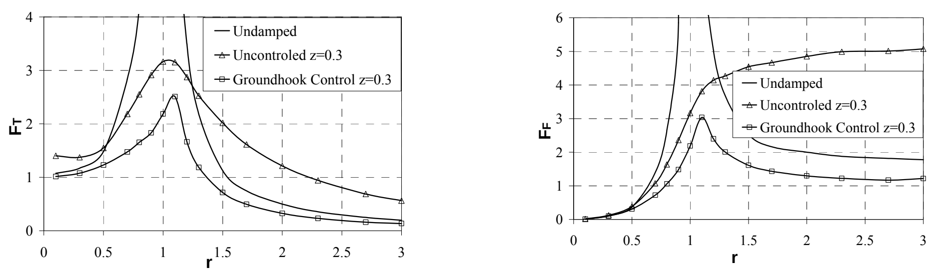

Fig. 8. Comparison between transfer functions of SDOF systems (undamped, linear damped and groundhook control) with harmonic base excitation

6. Conclusions

The numerical simulation results show that the semi-active control with groundhook strategy of SDOF systems with harmonic base excitation can provide better performance than uncontrolled SDOF systems, especially for higher dissipation coefficients. Therefore, in the case of groundhook strategy as well as in the case of skyhook strategy [7], in the resonance area these systems behave as strongly damped systems, but in isolation area, they behave as undamped ones.

In this case considered in the paper, the semi-active groundhook control strategy works better without other damping in parallel on the same suspension.

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