11th International Conference on Vibration Problems
Z. Dimitrovová *et al.* (eds.)
Lisbon, Portugal, 9-12 September 2013

DESIGN OF SEMI-ACTIVE ROLLER GUIDES FOR HIGH SPEED ELEVATORS

R.Monge*[1], J.M.Rodríguez-Fortún[1], A.Gómez[1], J.A.Roig[2], P.González[2]

[1]Technological Institute of Aragón
{rmonge, jmrodriguez, agomez }@ita.es

[2]MP Ascensores
{JAR, PGC}@ mpcorporacion.com

Keywords: High Speed Elevators, Semi-active Vibration Control, Magnetorheological Dampers.

Abstract. *Comfort is an important topic in the elevator industry, and between the different factors which affect it, vibration in the car is one of the most important. Passengers not only perceive this phenomenon as an unpleasant effect, but also as a signal of the elevator safety level, and therefore it is of great importance to mitigate it. Although mature technologies are available for reducing vibration in low speed elevators, the increased number of high buildings and sky-scrappers in emergent countries, forces the development of new technologies for medium and high speed elevators. Active vibration control techniques are widespread used for damping vibration in different industrial environment, but their application to the elevator industry normally imply expensive solutions, bulky and heavy actuators which highly burden its application. As alternative, the cheaper and lighter semi-active vibration systems based on passive elements capable of modifying their properties in response to external commands represent an appealing option. In this paper, we describe a design method for a semi-active roller guide based on a commercial magnetorheological damper. Different control strategies based on low cost acceleration sensors are also analyzed*

1 INTRODUCTION

Vibrations is an important problem in the elevator industry, affecting, not only the perception of the user with regard to the system safety and comfort, but also and most important, the system performance and reliability, as it affects the mechanical integrity of the different elements in the elevator and it can result in failure modes caused by fatigue. These effects are boosted in the new generation of medium to high speed elevators (>2.5 m/s), gaining special attention in the last years with the development of important and singular projects, with velocity values well above 8 m/s.

The origin of these vibrations can mainly be traced down to [5]: low frequency oscillations from the suspension cables [6] or an asymmetric load placing; or high frequency oscillations due to the guide rails, aerodynamic turbulence around the car or the movement of the passengers inside the cabin. Different methods have been developed for mitigating the vibrations, but two approaches are generally distinguished, passive and active vibration control. The first one relies on the use of passive elements, in the sense that they cannot enter energy into the system, for damping the oscillations. These elements are typically springs, dampers or even extra masses rightly placed. In contrast to this approach, active vibration control systems use actuators which input energy in the system. In the literature, interesting active approaches can be found using different types of actuators and strategies: roller guides isolation systems based on magnetic actuators are described in [4], linear actuators are selected for the same sort of application in [1]. Apart from isolation damping systems, [7] use an active mass damping system. The performance of active systems is normally much higher than the passive ones, being capable of eliminating the resonant behaviours without affecting the mitigation at higher frequencies and not too much reducing the stiffness of the system, but they are expensive, requiring high power density actuators, and a wrong design can result in system instabilities. For these reasons, the active vibration control systems are currently restricted to singular implementations or high cost elevators.

For this reasons, we present an intermediate solution between active and passive vibration control: a semi-active roller guide. The proposed system makes use of magnetorheological dampers in place of their passive counterpart [3], because of their capability for real time adaptation to the ride conditions, therefore improving the performance of passive approaches [2]. This system is not able to enter energy in the elevator and in consequence, apart from the price reduction with respect to the active solution, it cannot make the system unstable.

The present paper is divided as follows. In section 2, the design is described. The virtual and experimental validation appears in section 3, and finally, the conclusions and future lines of continuations are explained in section 4.

2 SYSTEM DESIGN

The prototype of an elevator with semi-active roller guides has been developed. The design contemplates two main elements:

- Hardware design: an existing roller guide is used as a basis for the design and is modified to include semi-active roller guides.
- Control design: the roller guide has to modify its behaviour in response to the rolling conditions. To do that, several strategies are evaluated with special attention to minimizing the number of sensors required.

2.1 Hardware design

The figure shows the design of the prototype roller guide. The device is installed in the two lower roller guides of the car because this location is closer to the standing point of the users and therefore they can better diminish the vibration from these roller guides resulting in a direct improvement in the comfort.

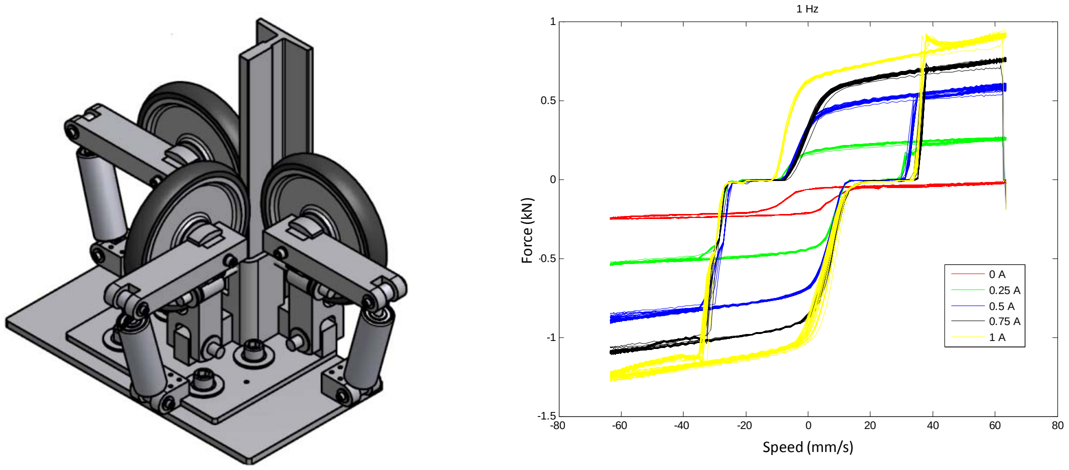

Figure 1: Prototype roller guide (left); response of magnetorheological damper (right).

As observed in the figure 1, the roller guide includes three magnetorheological dampers in parallel to the standard springs. These devices are controlled using current commands, and therefore three local controllers are embedded in the system for each damper. The response of the dampers can be observed in the figure 1 (right), which shows the force-speed curve of one damper. As it can be seen, an increase in the current results in a variation in the amplitude of the force.

2.2 Control design

For the evaluation of the different control options, the simplified 1-D model in the figure 2 is used.

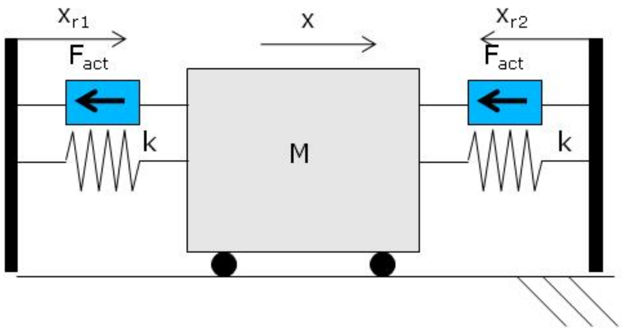

Figure 2: Simplified 1D model for the evaluation of the control options.

Different control algorithms have been evaluated during the project:

- Adjusted stiffness: the damper maintains a low stiffness value most of the time, only increasing it if the acceleration level exceeds a certain level for avoiding dead-end collisions:

$$Current = \begin{cases} I_{max}, acceleration > acceleration\ threshold \\ 0, acceleration \leq acceleration\ threshold \end{cases} \tag{1}$$

- Discrete sky-hook: the controller implements a classical sky-hook algorithm, only actuating when the damper dissipates power, remaining the current low in other conditions:

$$Current_{i=1,2} = \begin{cases} g\dot{x}, (\dot{x} - \dot{x}_{ri})\dot{x} > 0 \\ 0, (\dot{x} - \dot{x}_{ri})\dot{x} \le 0 \end{cases} \tag{2}$$

- Discrete on/off: similarly to (2) but in this case with constant feedback values:

$$Current_{i=1,2} = \begin{cases} I_{max}, (\dot{x} - \dot{x}_{ri})\dot{x} > 0 \\ 0, (\dot{x} - \dot{x}_{ri})\dot{x} \le 0 \end{cases} \tag{3}$$

- Speed feedback: the switch conditions in (2) are slightly modified:

$$Current_{i=1,2} = \begin{cases} g_v\dot{x}, (\dot{x} - \dot{x}_{ri})\ddot{x} > 0 \\ 0, (\dot{x} - \dot{x}_{ri})\ddot{x} \le 0 \end{cases} \tag{4}$$

- Acceleration feedback: this controller is equivalent to the sky-hook, with the difference of responding to the acceleration value. Like in that case, the switching condition is also based on the damper dissipating power or not.

$$Current_{i=1,2} = \begin{cases} g_a\ddot{x}, (\dot{x} - \dot{x}_{ri})\ddot{x} > 0 \\ 0, (\dot{x} - \dot{x}_{ri})\dot{x} < 0 \end{cases} \tag{5}$$

The figure 3 shows the response of the system to the different control algorithms above.

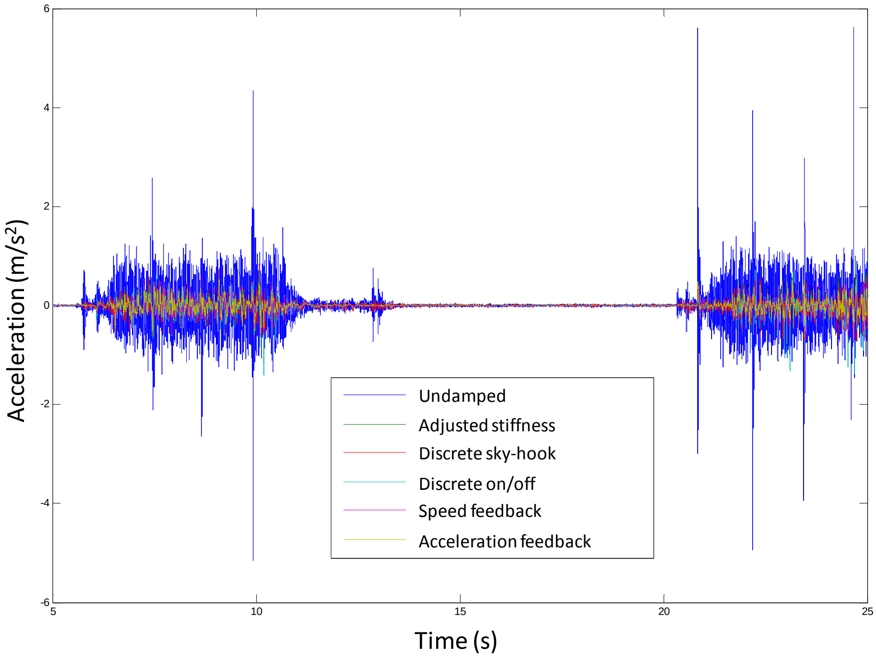

Figure 3: Response of the system to the different control algorithms.

Taking into account its simpler implementation, as it utilizes the already existing acceleration sensor in the car, and it does not require any integration operation which could derive in numerical errors, the acceleration feedback algorithm is chosen for implementation.

3 SYSTEM VALIDATION

The performance of the design is evaluated in two different ways:

- Using virtual models.
- Using experimental tests on a real elevator.

3.1 Virtual validation

The virtual validation is arranged using a complete 3D model of the vehicle implemented in the simulation software Matlab Simulink and the SimMechanics toolbox. The model can be observed in figure 4.

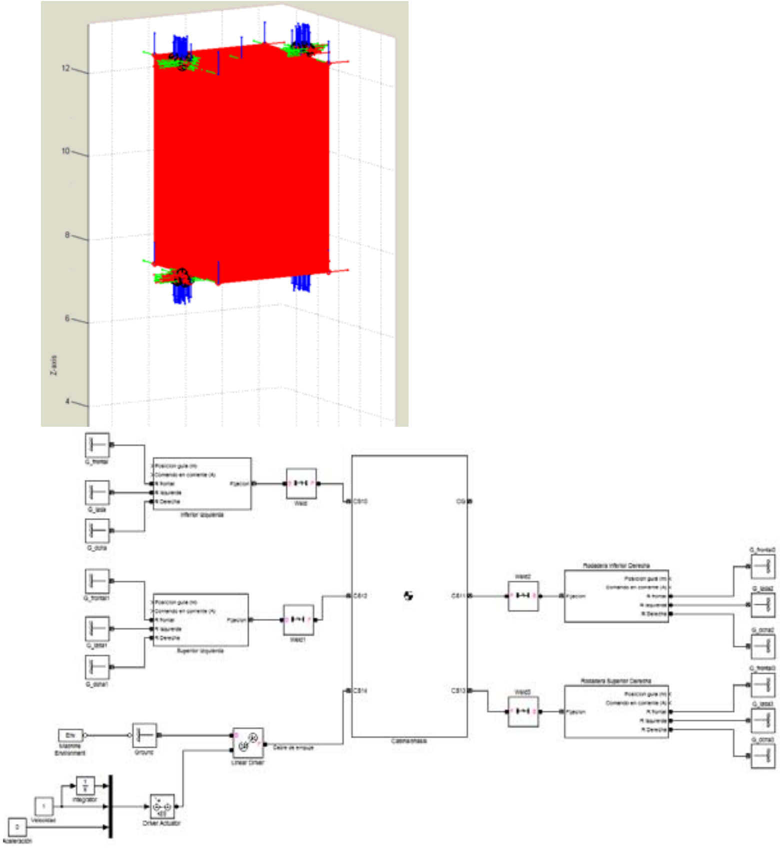

Figure 4: 3D elevator model in Matlab Simulink.

Figure 5 shows the behaviour of the system in three different conditions: without dampers, with the dampers working in open loop and with the acceleration feedback control. As observed, the installation of the dampers already mitigates the oscillation, but the higher improvement happens when the closed loop control is applied.

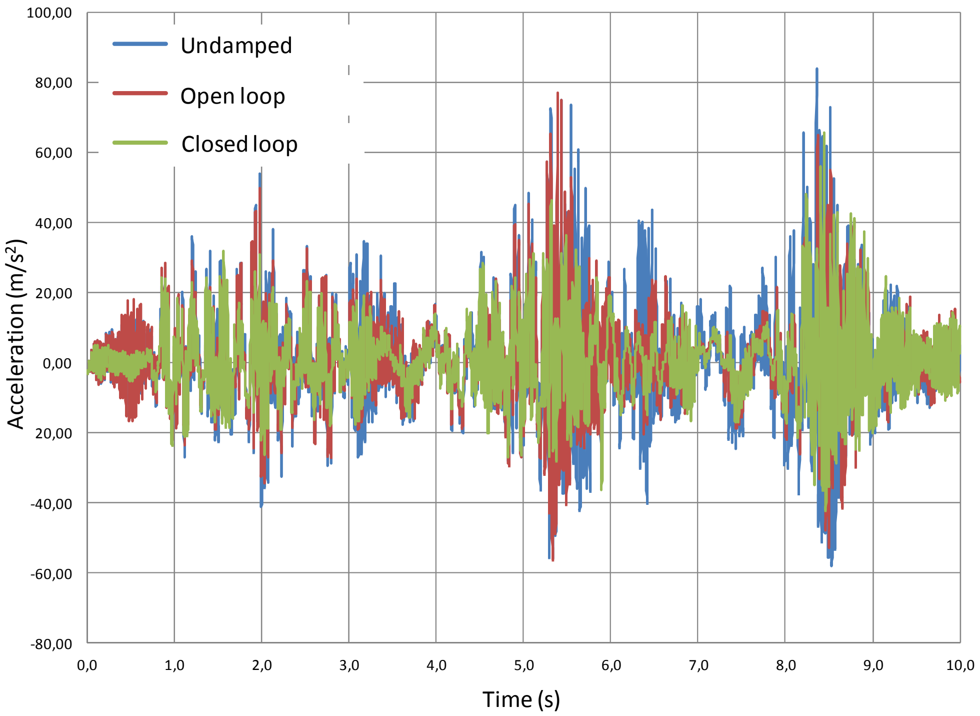

Figure 5: Virtual validation of the system.

3.2 Experimental validation

The designed roller guides have been implemented in a prototype elevator as can be shown in figure 6. For the experimental validation the angle of the dampers has been modified for increasing the torque exerted and maximizing its effect in the vehicle performance.

Figure 6: Implementation of prototype semi-active roller guides in an elevator.

Due to limitations in the control software at the prototype, the system is working with constant current. The implementation of the control algorithms will be arranged in further steps of the project. Figure 7 shows the oscillation reduction obtained when the damper is installed and different current levels are adjusted. As observed, the dampers reduce the oscillation level independently of the current level. This is caused by the device being in open loop conditions and the damping slope (figure 1) being only slightly affected by the current.

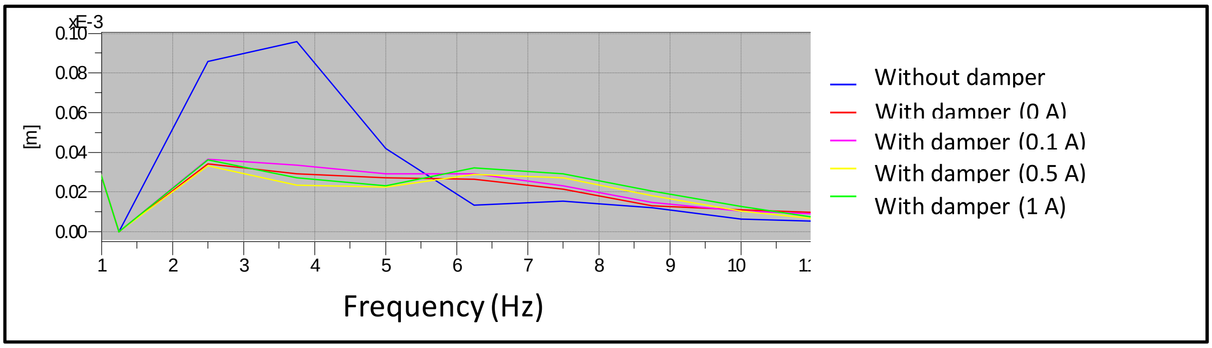

Figure 7: Oscillation levels during constant speed tests.

4 CONCLUSIONS

The present paper describes the activities developed during the design and validation of a semi-active roller guide system for high speed elevators. The proposed design implements three magnetorheological dampers in a three-axis roller guide and the effect of different control strategies has been evaluated with similar performances, being finally selected an acceleration feedback loop for the final implementation in the prototype.

The proposed system has been validated both using virtual models, and in a real prototype. In the first case, the effect of the control algorithm has been evaluated. In the second case, the validation is limited to open loop conditions due to limitations in the control hardware. In both cases, the installation of the dampers shows an important reduction of the oscillation level in the vehicle.

As future lines of activity, the closed loop control will be implemented in the prototype hardware for real time experimental validation and the prototype design will be improved for adapting it to series production.

5 ACKNOWLEDGEMENTS

The activities described in the present paper are part from the HASVAL Project (ADIA/10/501).

REFERENCES

[1] S. M. Rivas, E. A. Perondi, *Development of a controller for an active suspension system for high performance elevators.* ABCM Symposium Series in Mechatronics, vol. 3, pp. 46-55, 2008.

[2] S. M. Savaresi, C. Poussot-Vassal, C. Spelta, O. Sename, L. Dugard, *Semi-Active Suspension Control Design for Vehicles*. Elsevier 2010.

[3] M. C. Rodríguez, F. J. Elizondo, *Amortiguadores magnetoreológicos.* Ingenierías, v.1, no. 2 pp. 50-54 julio-diciembre 1998.

[4] K. Utsunomiya, K.-I. Okamoto, T. Yumura, K.Funai, H.Kuraoka, *Active roller guide system for high-speed elevators*. Elevator World, 2002.

[5] A. S. Hamdy, *Active damping of vibrations in elevator cars*. PhD from the Swiss Federal Institute of Technology Zurich, 1997.

[6] M. Otsuki, K. Yoshida, K. Nagata, S. Fujimoto, T. Nakagawa, *Experimental study of vibration control for rope-sway of elevator of high-rise buildings.* Proceedings of the American Control Conference, 2002.

[7] N. Teshima, K. Kamimura, M. Hirai, M. Nagai, T. Kamada, *Vibration control of ultra high-speed elevator by active mass damper (2nd report, Experiments using a Full-scale test facility)*. Transactions of the Japan Society of Mechanical Engineers Series C, vol. 66, 2000.