CONEM 2016 CONGRESSO NACIONAL DE ENGENHARIA MECÂNICA
21 - 25 AGOSTO DE 2016 FORTALEZA - CEARÁ

FUZZY CONTROL APLIED IN SUPPRESSION OF VIBRATIONS IN A NONLINEAR LIFT SYSTEM

Leandro Camargo Claro Dos Santos, leandrocamargoclaro@gmail.com[1]
Angelo Marcelo Tusset, a.m.tusset@gmail.com[1]
Frederic Conrad Janzen, fcjanzen@utfpr.edu.br[1]
Vinícius Piccirillo, piccirillo@utfpr.edu.br[1]
Jose Manoel Balthazar, jmbaltha@gmail.com[2]
Rodrigo Tumolin Rocha, digao.rocha@gmail.com[3]

[1]UTFPR, Av. Monteiro Lobato, s/n, km 04 - CEP 84016-210 - Ponta Grossa-PR-Brazil
[2]UNESP-ITA, Praça M.al Eduardo Gomes, 50 - Vila das Acácias. CEP 12.228-900-São José dos Campos-SP- Brazil
[3]UNESP, Av. Eng. Luiz Edmundo C. Coube, 14-01, Bauru-Brazil

Abstract: *In this work, the horizontal dynamic response and the semi-active control of a vertical transportation system is analyzed under random excitation by guide rail deformations. In order to improve the comfort for passengers, a control strategy based on fuzzy control using MR damper is used. The control force of the damper is a function of the voltage applied in the coil of the MR damper that is based on the force given by the controller. Numerical simulations confirm that the control strategy using MR damper can be effective in reduce the vibration of the vertical transport..*

Keywords: *Fuzzy control, Vertical Transportation, MR damper.*

1. INTRODUTION

High-speed elevators became a necessity, however, high speeds can result in decreased quality of ride (Mitsui and Nara, 1971), this being one of the main problems in the high-speed elevators systems (Nai et al., 1994). Thus, it is necessary improve the travel quality, without losing the efficiency of elevators and there are limits of the levels of horizontal and vertical vibrations, lateral and longitudinal acceleration and jerk, necessary to ensure good ride quality to passengers (Fortune, 1997).

This paper presents the fuzzy control strategy of a nonlinear vertical transportation system model using a magnetorheological (MR) damper. The fuzzy control problem is formulated in order to design the damping force control signal for a suspension system. Then the values of the control damping force functions are transformed into electrical control signals using fuzzy control.

The mechanism of the magnetorheological damper is similar to the mechanism of the hydraulic shock absorbers which force is caused due to the passage of fluid through an orifice. This variable resistance to fluid flow allows using the magnetorheological fluid in viscous and other electrically controllable devices. Thus the magnetic properties of the fluid allow its use as a damper controlled by an electric voltage [volts] or an electric current [Amps] (Tusset et al., 2009, 2012).

For the use of MR damper, in the suppression of unwanted oscillations variable, which it can be controlled is the electrical current or voltage, which changes the viscosity of the fluid's internal damper. The damping force will depend on the speed of the piston of the damper and the density of internal fluid.

The feedback of state variables by means of sensors can provide information about the behavior of the controlled system, over time and thereby on the optimal intensity of force being applied by the MR damper. Here, we will utilize a mathematical model to transform the values of force control in electric current signal proposed by (Tusset el al., 2009).

2. MATHEMATICAL MODEL FOR NONLINEAR LIFT SYSTEM

Figure 1a shows the schematic diagram of the cabin elevator, where the roller guides support the platform with springs to avoid the transmission of the external excitation caused by misalignment and deformation of guide rails. And figure 1b shows an equivalent physical model to represent the horizontal motions of an elevator system.

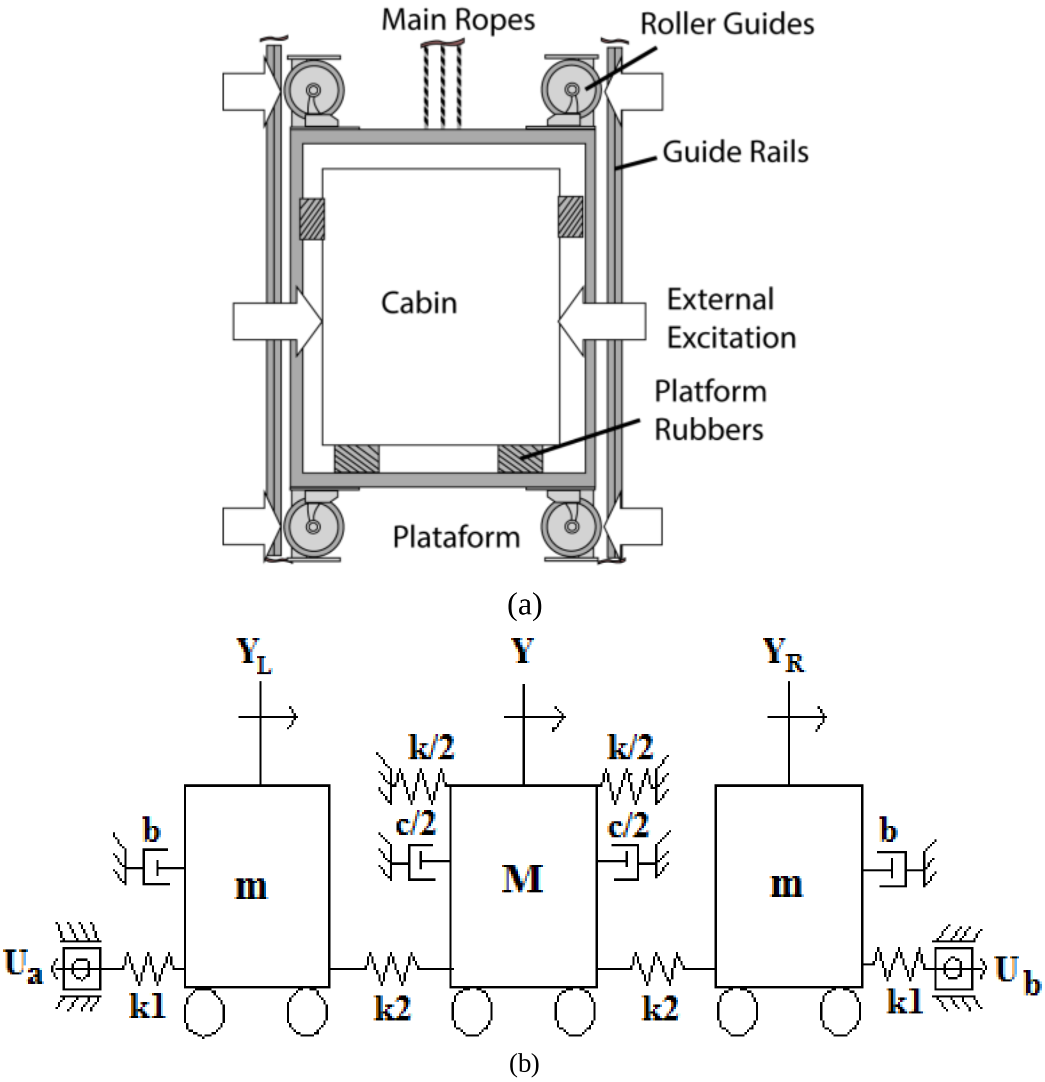

Figure 1. (a) Schematic diagram of cabin structure (adapted from Funai, 2004). (b) Equivalent model for the horizontal motion of the elevator (adapted from Lopez et *al*., 2010).

In this model, M is the mass of the cabin [kg], m is the mass of the suspension system [kg], b is the damping coefficient of the suspension [N.s/m], c is the damping coefficient of the cabin [N.s/m], k_1 is the stiffness coefficient of the guide rollers [N/m], k_2 is the stiffness coefficient of the suspension [N/m], k is the stiffness coefficient of the spring equivalent to tilting motion of the cabin [N/m], Y is the displacement of the cabin [m], Y_L is the displacement of the left suspension system [m], Y_R is the displacement of the right suspension system [m]. U_a and U_b are external excitations caused by guide rails deformations, defined in Eq. (1).

$$U_a = U_b = a(r(t)) \tag{1}$$

where: a is the maximal amplitude of external excitation [m], and $r(t)$ are normally distributed random functions..

The equations of motion that represent the vertical transportation system can be represented by:

$$\begin{aligned} m\ddot{Y}_L + b\dot{Y}_L + (k_1 + k_2)Y_L - k_2 Y &= k_1 U_a \\ M\ddot{Y} + c\dot{Y} + 2k_2 Y + kY^3 - k_2 Y_L - k_2 Y_R &= 0 \\ m\ddot{Y}_R + b\dot{Y}_R + (k_1 + k_2)Y_R - k_2 Y &= k_1 U_b \end{aligned} \tag{2}$$

Or in space of estate:

$$
\begin{aligned}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= -\alpha_2 x_1 - \alpha_1 x_2 + \alpha_3 x_3 + \alpha_4 U_a \\
\dot{x}_3 &= x_4 \\
\dot{x}_4 &= \beta_3 x_1 - \beta_2 x_3 - \beta_5 x_3^3 - \beta_1 x_4 + \beta_4 x_5 \\
\dot{x}_5 &= x_6 \\
\dot{x}_6 &= \alpha_3 x_3 - \alpha_2 x_5 - \alpha_1 x_6 + \alpha_4 U_b
\end{aligned}
\tag{3}
$$

where: $x_1 = Y_L$, $x_2 = \dot{Y}_L$, $x_3 = Y$, $x_4 = \dot{Y}$, $x_5 = Y_R$, $x_6 = \dot{Y}_R$, $\alpha_1 = \frac{b}{m}$, $\alpha_2 = \frac{(k_1 + k_2)}{m}$, $\alpha_3 = \frac{k_2}{m}$, $\alpha_4 = \frac{k_1}{m}$, $\beta_1 = \frac{c}{M}$, $\beta_2 = \frac{2k_2}{M}$, $\beta_3 = \frac{k_2}{M}$ $\beta_4 = \frac{k_2}{M}$ and $\beta_5 = \frac{k}{M}$.

Consider, now, the introduction of the MR damper controlled in parallel with the spring roller guides as shown in figure 2.

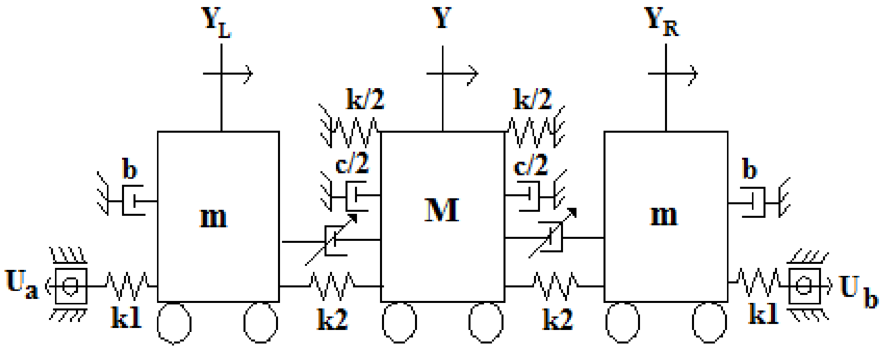

Figure 2. Equivalent model for the horizontal motion of the elevator whit MR damper.

The system (3) with the introduction of active control can be represented by the following system:

$$
\begin{aligned}
\dot{x}_1 &= x_2 \\
\dot{x}_2 &= -\alpha_2 x_1 - \alpha_1 x_2 + \alpha_3 x_3 + \alpha_4 U_a + \delta_1 u_1 \\
\dot{x}_3 &= x_4 \\
\dot{x}_4 &= \beta_3 x_1 - \beta_2 x_3 - \beta_5 x_3^3 - \beta_1 x_4 + \beta_4 x_5 - \delta_2 (u_1 + u_2) \\
\dot{x}_5 &= x_6 \\
\dot{x}_6 &= \alpha_3 x_3 - \alpha_2 x_5 - \alpha_1 x_6 + \alpha_4 U_b + \delta_1 u_2
\end{aligned}
\tag{4}
$$

where: u_1 and u_2 represent the MR damper force, $\delta_1 = \frac{1}{m}$ and $\delta_2 = \frac{1}{M}$.

Figure 3 it shows the main characteristics of the variation of the force of the damper in function of both velocity and electric current applied to the coil of the damper, noting that u_1 and u_2 is the force [N], (i) is the electric current [A] and v is the velocity of the displacement of the piston of the damper [m/s] (Tusset *et al.*, 2012).

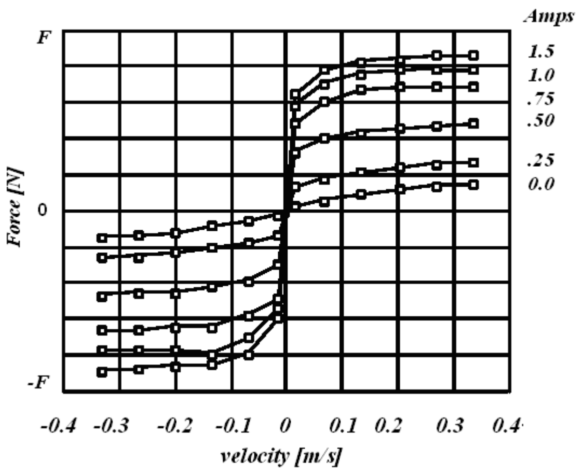

Figure 3. Characteristics of the normalized force-velocity of a MR damper in function of the current (Tusset *et al.*, 2009, 2012)

In Fig. 3 it can be observed variation characteristics of damping force depending on the speed of displacement of the damper piston and electric current applied to the coil. One way to determine the electric current applied to the coil is via Fuzzy Control (Tusset el al., 2009).

In Figure 4a, 4b and 4c it can be observed membership functions for velocity [m/ s], force [N] and current [Amps] as well as the type of membership function and its superposition.

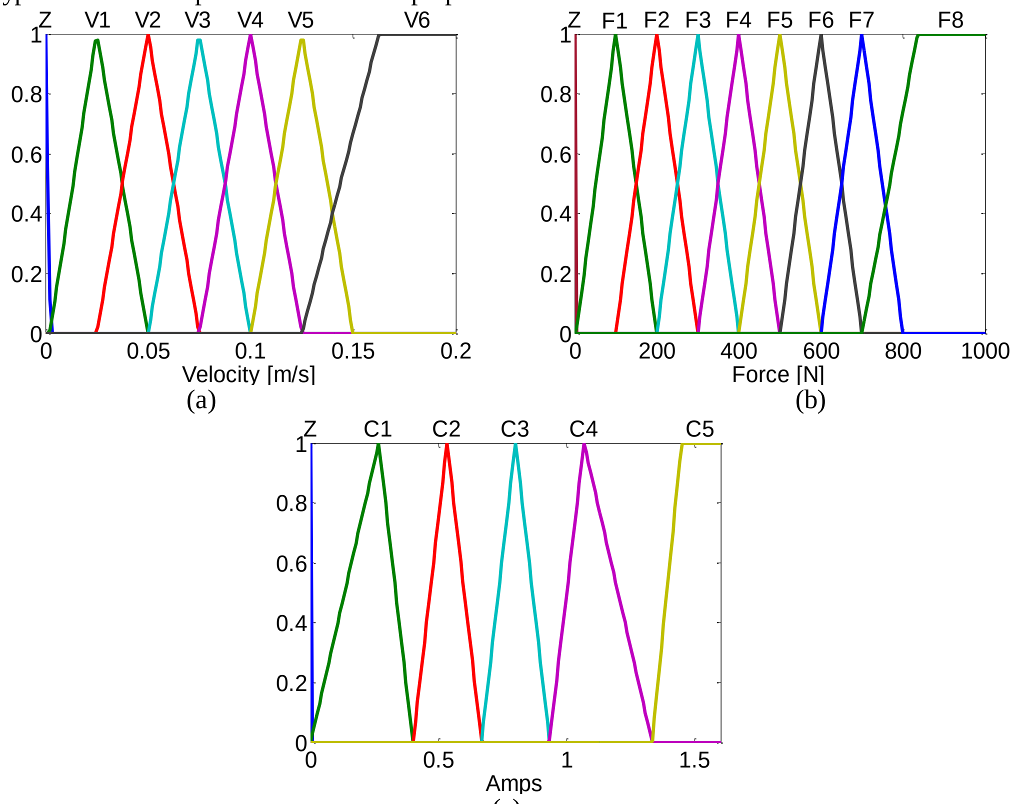

Figure 4. (a) Input membership function (Velocity). (b) Input membership function (Force). (c) Output membership function (Amps).

For calculating the defuzzification was defined minimum for the method (and) maximum for the method (or) implication minimum, maximum aggregation, and performing the defuzzification (centroid).

The consequent application in the fuzzy control will be obtained as follows:

If (Velocity is ...) and (Force is ...) then (Amps is ...).

The rules to be applied can be seen in Table 1.

Table 1. Map of fuzzy rules for the current control (Tusset el al., 2009).

VELOCITY

FORCE / Amps	Z	V1	V2	V3	V4	V5	V6
Z	Z	Z	Z	Z	Z	Z	Z
F1	C1	Z	Z	Z	Z	Z	Z
F2	C1	C1	C1	C1	C1	C1	C1
F3	C2	C2	C2	C1	C1	C1	C1
F4	C3	C2	C2	C2	C2	C2	C2
F5	C4	C3	C2	C2	C2	C2	C2
F6	C5	C4	C3	C3	C3	C3	C3
F7	C5	C5	C4	C4	C3	C3	C3
F8	C5	C5	C5	C5	C5	C5	C5

In Fig. 5 we can observe the rules represented by Table 1 and the membership functions shown in Fig. 4.

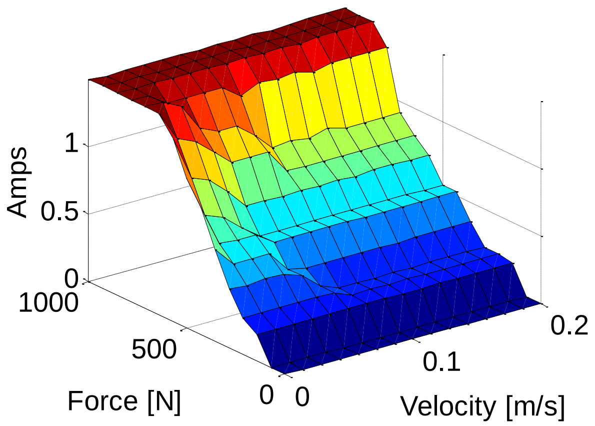

Figure 5. Fuzzy rules for the current control

Figure 5 illustrates the variation of the electric current applied to the coil MR damper, according to the variation of the damping piston speed and power estimated by the proposed fuzzy control.

3. DETERMINATION OF FORCE OF THE MR DAMPER BY FUZZY CONTROL

For determination of the proposed fuzzy control was used the classical Mamdani, with five membership functions with a symmetrical and evenly spaced in order to smooth out any discontinuities of strength and minimize problems such as bumps and noises. The choice of the membership functions (velocity) and (relative velocity) is due to the fact that the relationship between them to determine the level of damping between *m* and *M*.

Figures 6a, 6b and 6c are defined membership functions relating to velocity, relative velocity and actuation Force $u_{1,2}$.

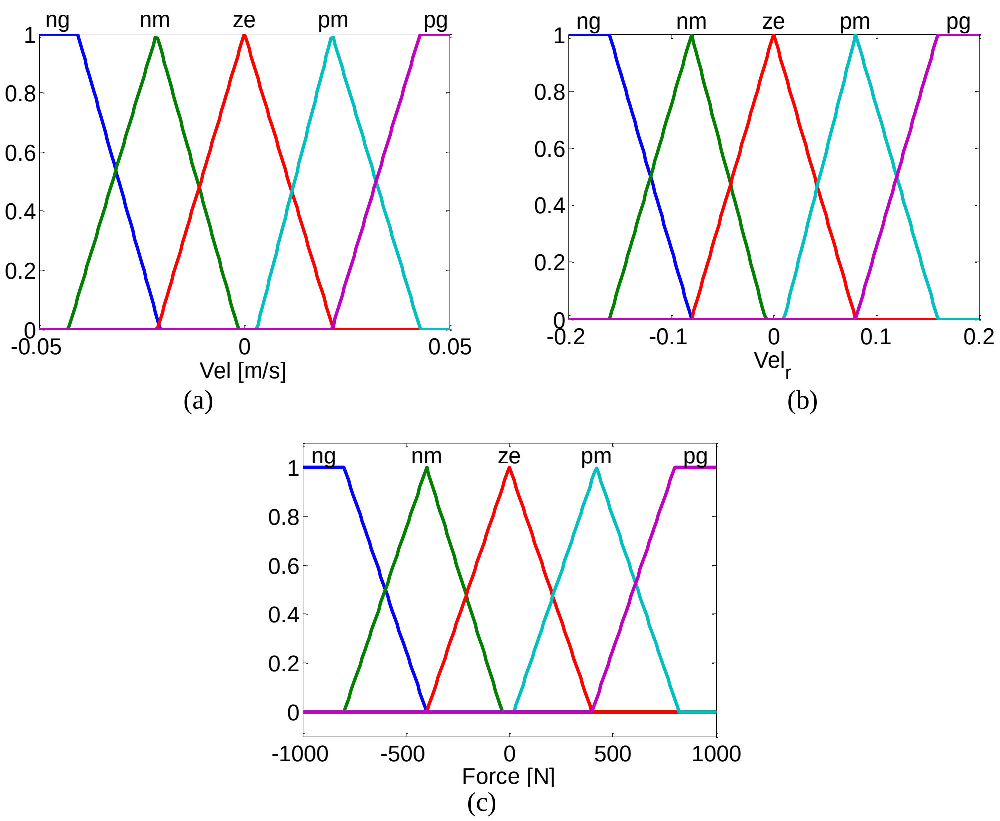

Figure 6. (a) Input membership function (Velocity). (b) Input membership function (Relative Velocity). (c) Output membership function (Force).

For calculating the defuzzification was defined minimum for the method (and) maximum for the method (or) implication minimum, maximum aggregation, and performing the defuzzification (centroid).

The consequent application in the fuzzy control will be obtained as follows:

If (Velocity is ...) and (Relative Velocity is ...) then (Force is ...).

The rules to be applied can be seen in Table 2.

Table 2. Map of fuzzy rules for the force control.

F		***V***				
		NG	*NM*	*ZE*	*PM*	*PG*
V_{rel}	*NG*	NG	NG	NM	NM	NM
	NM	NG	NM	NM	NM	NM
	ZE	NM	NM	ZE	PM	PM
	PM	PM	PM	PM	PM	PG
	PG	PM	PM	PM	PG	PG

In Fig. 7 we can observe the rules represented by Table 2 and the membership functions shown in Fig. 6.

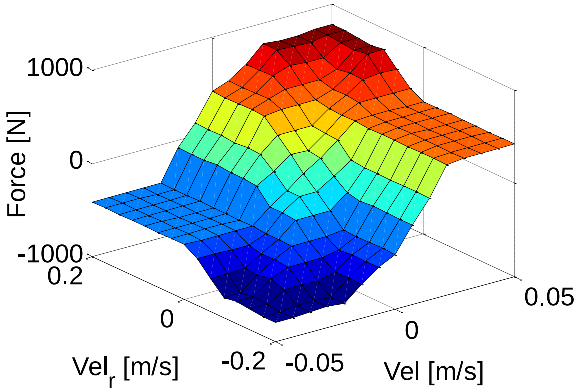

Figure 7. Fuzzy rules for the force control

Figure 7 illustrates the variation of force that must be applied by the MR damper according to the variation of the lateral displacement speed of the elevator, and the difference between the lateral displacement speed of the elevator, and displacement speed of the lift roller.

4. NUMERICAL SIMULATION

Table 3 show the parameters experimentally obtained, used for numerical simulations.

Table 3 show the parameters used for numerical simulations (Rivas and Perondi, 2010; Santo *et al.*, 2014).

Parameters	Unit	Description	Value
M	kg	Mass of the cabin	1120
m	kg	Mass of the suspension system	17.5
b	N.s/m	Damping coefficient of the suspension	668.21
c	N.s/m	Damping coefficient of the cabin	2058.2
k_1	N/m	Stiffness coefficient of the guide rollers	250000
k_2	N/m	Stiffness coefficient of the suspension	19027
k	N/m	Stiffness coefficient of the spring equivalent to tilting motion of the cabin	19027
a	m	External excitation amplitude	0.01

In Fig. 8, can observe the behavior of the elevator car (x_3), considering the speed of the piston MR damper obtained from ($V = x_2 - x_4$ for displacement of the left and $V = x_6 - x_4$ for displacement of the right) and the force of variation MR damper obtained by fuzzy control (Table 2), considering the variation the current applied to the coil of MR damper obtained by fuzzy control (Table 1).

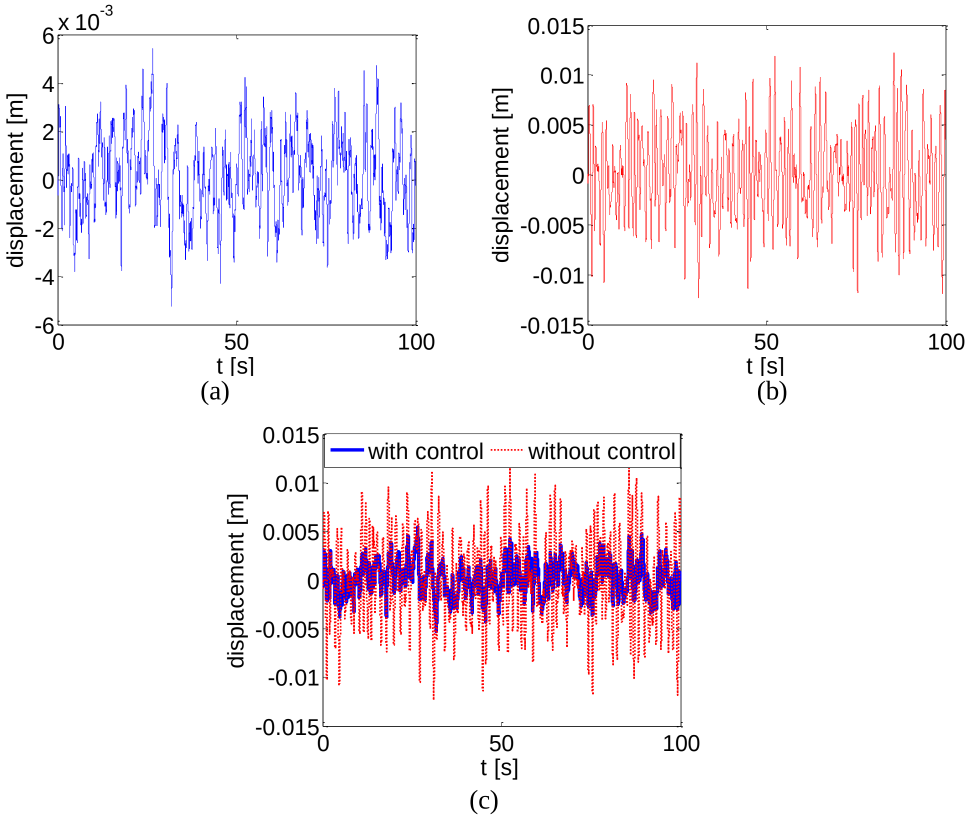

Figure 8. Displacement of the elevator car (x_3). (a) With fuzzy control. (b) Without fuzzy control. (c) Comparison between the displacements.

As can be seen in Figure 8, the fuzzy control has reduced horizontal displacement of the elevator (maximum displacement=0.012318 [m] and displacement in RMS= 0.004349 [m]) to (maximum displacement=0.005417 [m] and displacement in RMS= 0.001682 [m]), showing the contribution of the proposed control. In Fig. 9 are shown the Force applied on the left MR damper at right MR damper, and the respective electric currents.

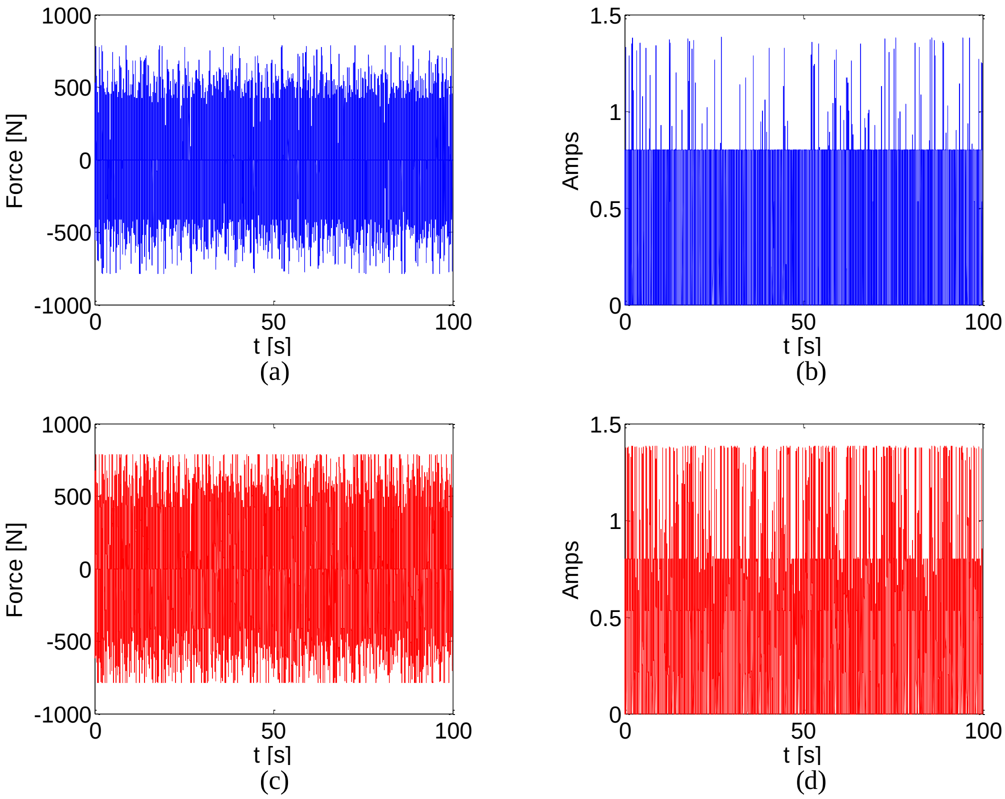

Figure 9. Force and Amps applied in Fuzzy control. (a) Force applied in u_1. (b) Amps applied in damper MR_1. (c) Force applied in u_2. (d) Amps applied in damper MR_2.

It is possible to observe in Fig. 9 that both the force and the current varied according to external random inputs.

5. CONCLUSIONS

This work presented the horizontal behavior of a vertical transportation system random excited by guide rails, as well as a proposal for a control by MR damping. The fuzzy control technique used proved reducing cabin's vibration and contributing on prevention of elevator's components integrity.

Using the mathematical model to transform the values of force control in electric current signal proposed by (Tusset el al., 2009), it was possible to control the coil voltage of the MR damper. We can conclude that in general the proposed active control is appropriate and efficient, because it does not need to obtain functions of analytically obtained control because the rules set apply to any variation of the nonlinear components of the model, and the active system depends on only variation of the lift speed and the roller speed.

6. ACKNOWLEDGEMENTS

The authors thank CAPES, FAPESP and CNPQ (proc: 447539/2014-0).

7. REFERENCES

Fortune, J.W. 1997. “Mega-High Rise elevatoring”. ElevatorWorld.

Funai, K., Katayama, H., Higaki, J., Utsunomiya, K., Nakashima, S., 2004. “The Development of Active Vibration Dampers for Super High-Speed Elevators”. In Proceedings of the 14th International Congress on Vertical Transportation Technologies, Instanbul, Turkey, pp. 1-1.

Lopez, S. M. R., Perondi, E. A., Sobrinho, M. R. S., 2010. “Adaptive control for an active suspension of an elevator”. In ABCM Symposium Series in Mechatronics, Vol. 4, pp. 62-71.

Rivas, S.M., Perondi, E.A., 2010. “Adaptive Control for an Active Suspension of an Elevator”. ABCM Symposium Series in Mechatronics, Vol. 4 , pp. 62-71.

Santo, D.R., Balthazar, J.M., Pontes Jr, B.R., Silveira, M., Tusset, A.M., 2014, “Dinâmica do movimento horizontal de um sistema de transporte vertical excitado harmonicamente pelos trilhos de guia”. In Congresso Nacional de Engenharia Mecânica, CONEM 2014. Uberlândia. pp. 1-10.

Mitsui, N., Nara, T., 1971. “Analysis of horizontal quaking of high-speed elevators”. Vol. 8. Hitachi Review.

Nai, K., Forsythe, W., Goodall, R. M., 1994. “Vibration reduction techniques for high speed passenger elevators”. In Proceedings of the Third IEEE Conference on Control Applications, pp. 965-970.

Tusset, A.M., Rafikov, M., Balthazar, J.M., 2009. “Intelligent controller design for magnetorheological damper based on quarter-car model”. Journal of Vibration and Control, Vol. 15, pp.1907-1920.

Tusset, A.M., Balthazar, J.M., Chavarette, F.R., Felix, J.L.P., 2012. “On energy transfer phenomena, in a nonlinear ideal and nonideal essential vibrating systems, coupled to a (MR) magneto-rheological damper”. Nonlinear Dynamics, Vol. 69, pp. 1859-1880.

8. AUTHORIAL RESPONSIBILITY

“The authors are solely responsible for the content of this work”.