

An analysis of the oscillatory movements of the suspension ropes for an elevator with parabolic speed modeling and continuous deceleration

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Abstract. In order to insure passengers' security and smooth functioning, elevators benefit from speed modeling. The paper aims to compare the evolution of the kinematic parameters (acceleration, speed, amplitude) of the oscillatory movements performed by the suspension ropes of the elevator cabin, considering speed variation at start and stop realized using S – curves generated from arches of parabolic curves. Usually, the functioning cycle of an elevator ends with a short period of constant speed traveling, in order to insure levelling of the cabin. We have already made a comparative analysis of the oscillatory movements of the suspension ropes, considering three varieties of speed modeling: with trapezoidal variation of acceleration, with parabolic variation of acceleration and with cosinusoidal variation of acceleration. The paper aims to analyze the possibility to remove the levelling period, and the impact of this upon the kinematic parameters of the oscillatory movements performed by the suspension ropes. We will take into consideration two possibilities of deceleration: with levelling step and with continuous variation of speed. In both cases, for comparison, the same duration of the acceleration period and deceleration period will be considered.

1. Introduction

Speed control, using electronic devices such as frequency convertors, introduced the possibility of accelerating and decelerating the elevators using the so called S curves, which can ensure a smooth variation of speed and acceleration, in order to increase comfort and avoid oscillations of the suspension ropes, generated by shocks. In order to generate S curves, various curves were used, such as polynomial and trigonometric ones [1], [2].

Kinematic parameters of an elevators functioning cycle are speed, acceleration and its derivate, jerk. The functioning cycle of an elevator is divided in three time periods: accelerating time, the period of constant speed travel, and deceleration time. Usually, the last one has three intervals: decelerating, constant speed step, and stop time. We will compare the influence on the kinematic parameters of the oscillatory movements performed by the suspension ropes if deceleration is realized with levelling step and with continuous speed [3], [4].

The time evolution of each parameter was already studied in both cases of deceleration defined above, considering two possibilities of generating S curves by speed control: using arches of parabola and arches of cosinusoidal curve [5].



2. Technical considerations

2.1. The dynamic equation of motion

A theoretical analysis of the cabin's motion during a functioning cycle can be performed starting from the model presented in Figure 1. The cabin has a complex motion, resulted from the superposition of a dampened oscillatory motion over the theoretical linear motion, since suspension cables act like elastic elements [5], [6].

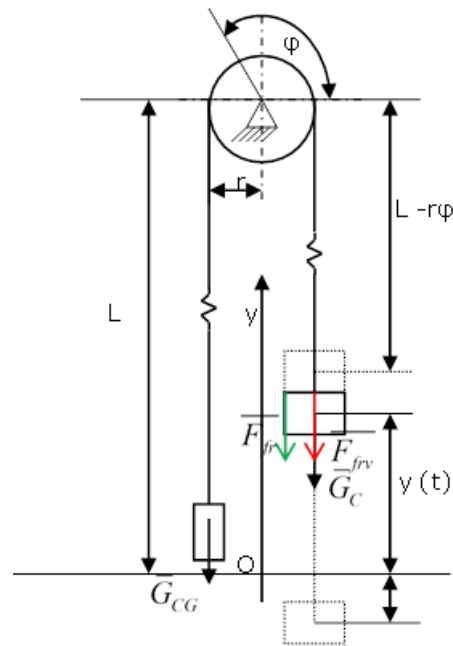


Figure 1. The theoretical model of the elevator

The Dynamic equation of the cabin's motion was elaborated under the following hypothesis: [5-7]

- Only the cabin's movements will be studied, the oscillatory movements of the counterweight and of the friction wheel will be neglected.
- The equation was written only for the vertical motion, defined as axis Oy.
- The weight of the suspension ropes was not taken into consideration.
- The suspension cables were considered elastic elements having a variable stiffness coefficient.
- The damping coefficient of the cables was not taken into consideration.
- The influence of the cabin's suspension system was not considered.

The suspension cable's elasticity coefficient is:

$$k = \frac{E \cdot A}{L - r \cdot \varphi} \quad (1)$$

where:

- E is Young's modulus of the cable,
- L is the initial length of the cable,
- A is the cable's section area
- r is the radius of the friction wheel,
- φ is the rotation angle of the wheel at moment t.

Value $r\varphi$ is corresponding to the theoretical displacement of the cabin, considering suspension ropes inextensible.

The dynamic equation of the cabin's motion can be written as follows:

$$M \cdot \ddot{y} = -M \cdot g + k \cdot (r \cdot \varphi - y) - F_{frv} - F_{fr} \quad (2)$$

where M is the mass of the fully loaded cabin, and $y(t)$ is the real (absolute) displacement, measured from ground level, resisting forces are:

- aerodynamic friction force,

$$F_{frv} = 1,2 \frac{v_{\max}^3}{27} B \cdot C \quad (3)$$

- dry (coulombian) friction force, due to contact with the slips,

$$F_{fr} = \mu \cdot N \quad (4)$$

The dynamic equation of the cabin becomes: [2], [3]

$$M \cdot \ddot{y} = -M \cdot g + \frac{E \cdot A}{L - r \cdot \varphi} (r \cdot \varphi - y) - 1,2 \frac{v_{\max}^3}{27} B \cdot C - \mu \cdot N \cdot \text{sgn}(\dot{y} - r \cdot \dot{\varphi}) \quad (5)$$

2.2. The parameters variation

In order to compare the two types of deceleration, the parameters taken into consideration are the cable elongation and the acceleration. As the fully loaded cabin climbs, the cable length decreases, and its stiffness increases. Hence, the cable's elongation diminishes, and the cabin will accelerate upwards, even if at constant speed. Considering the same time duration for accelerating and decelerating, the time duration of the constant speed period was calculated, for both cases of speed modeling: using arches of parabola and using arches of cosinusoidal curves, and for both cycle types: with and without constant speed step at deceleration.

The study was performed using the parameters of an elevator for personnel, serving 8 levels (22.5 meters), designed for the transportation of 4 people (3000 N weight). Parameters values are: [8]

$M = 950 \text{ kg}$,

$E = 89 \text{ GPa}$,

$L = 27.3 \text{ m}$,

$A = 31 \text{ mm}^2$,

$v_{\max} = 1 \text{ m/s}$,

$B \cdot C = 0.882 \text{ m}^2$,

$\mu = 0.15$,

$N = 428 \text{ N}$.

Considering the equations of variation for the kinematic parameters, at hoisting the fully loaded cabin, the following diagrams were obtained using MatLab ode113 routine (Figures 2 to 9). In order to better understand differences, although diagrams were generated for an entire functioning cycle, figures present only deceleration period.

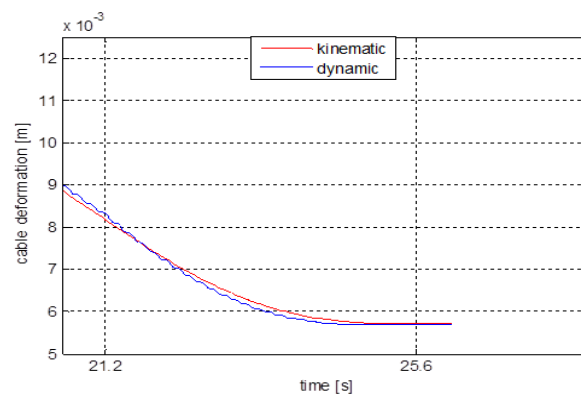


Figure 2. Cable deformation in the case of parabolic modeling of speed, with continuous deceleration

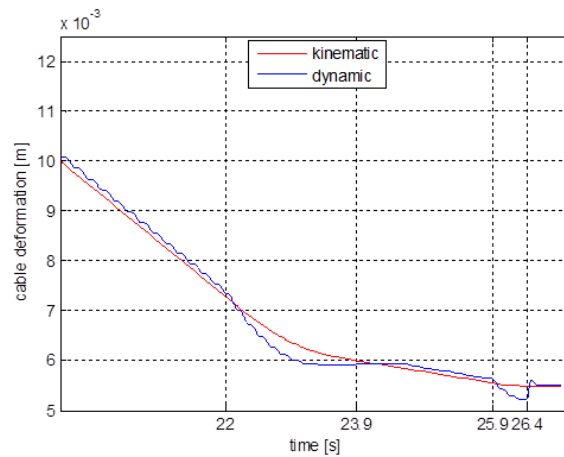


Figure 3. Cable deformation in the case of parabolic modeling of speed, with levelling step at deceleration

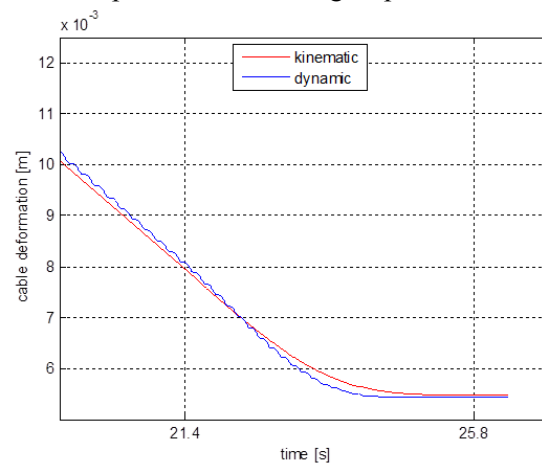


Figure 4. Cable deformation in the case of cosinusoidal modeling of speed, with continuous deceleration

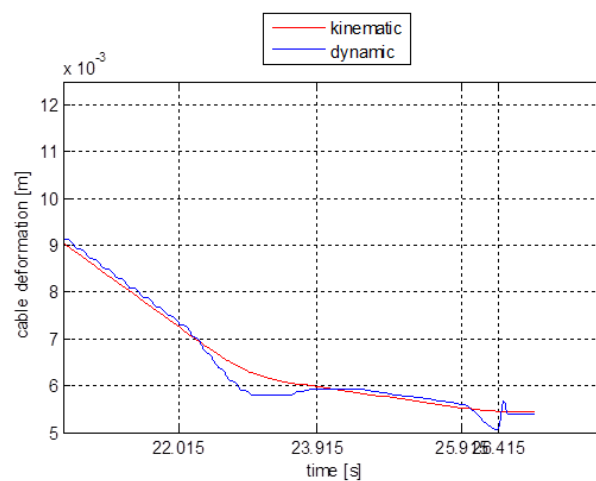


Figure 5. Cable deformation in the case of cosinusoidal modeling of speed, with levelling step at deceleration

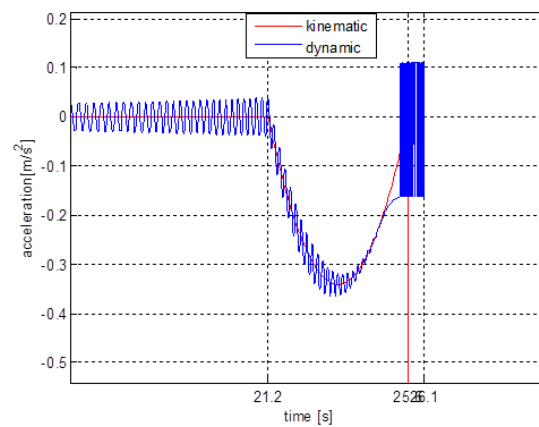


Figure 6. Acceleration in the case of parabolic modeling of speed, with continuous deceleration

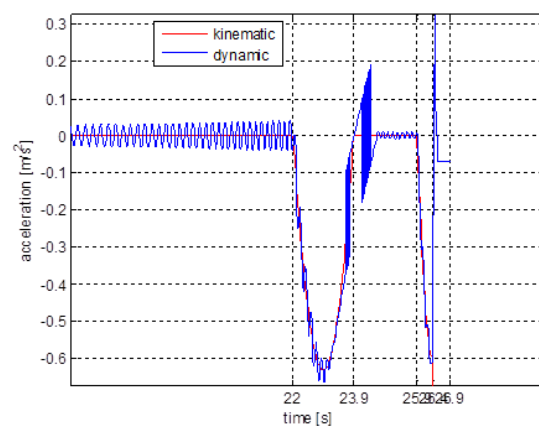


Figure 7. Acceleration in the case of parabolic modeling of speed, with levelling step at deceleration

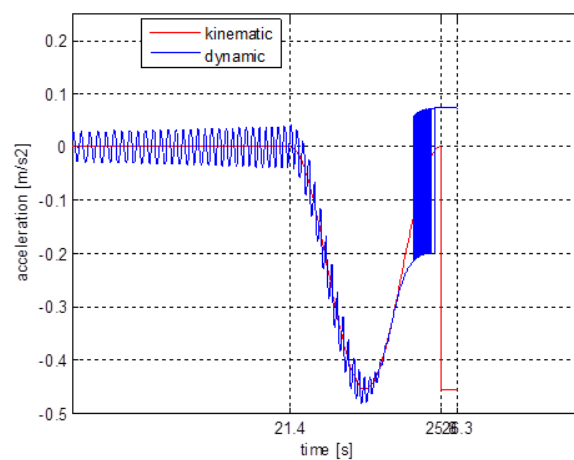


Figure 8. Acceleration in the case of cosinusoidal modeling of speed, with continuous deceleration

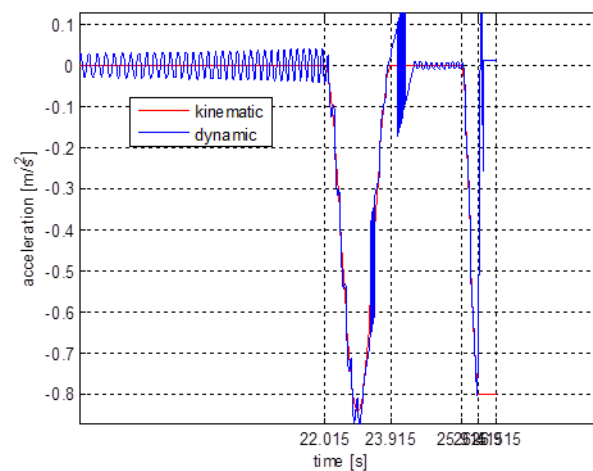


Figure 9. Acceleration in the case of parabolic modeling of speed, with levelling step at deceleration

Table 1. Dynamic parameters values

Parameter	Parabolic		Cosinusoidal	
	With levelling	Continuous	With levelling	Continuous
Time [s]	4.4	4.4	4.4	4.4
Acceleration [m/s ²]	0.625	0.340	0.833	0.454
Jerk [m/s ³]	1.330	0.3099	1.392	0.3245

3. Interpretation and conclusions

Analyzing the diagrams above one can notice that the continuous deceleration significantly reduces cable deformation due to the oscillatory movements of the suspension cables. The variation of acceleration due to the cable elasticity is also reduced in the case of continuous deceleration; hence the dynamical solicitations of the cable are smaller. This is a consequence of the lowest theoretical value of acceleration that can be used when decelerating without levelling step. As shown in Table 1, cosinusoidal modeling of speed conduces, at same time duration of the decelerating period, to higher values of acceleration. Diagrams of deformation and acceleration show that residual oscillations of the cable are diminished in the case of continuous deceleration. Positioning precision, in correlation with the controller, is to be analyzed.

The hypotheses formulated at the beginning of chapter 2 are suitable only for light loads and small travels and speed. The dynamic equation of motion for other values of these parameters should be rewritten, considering the dynamical processes that occur during a functioning cycle [9], [10].

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