CONSIDERATIONS ON THE KINEMATICS OF AN ELEVATOR WITH SPEED MODELING AND CONTINUOUS DECELERATION

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Abstract: The paper intents to compare the evolution of the kinematic parameters of an elevator with electronic modeling of speed, considering to possibilities of deceleration: with levelling step and with continuous variation of speed. In both cases, it will be considered the same duration of deceleration. In order to better validate the results, comparison will consider two speed modeling varieties: parabolic variation and cosinusoidal variation.

Key words: Elevator, speed control, jerk, acceleration.

1. INTRODUCTION

Classical approach of elevators designing starts from their functioning cycle. In order to insure an optimal alignment of the cabin at the floor, deceleration period has a short step of very low constant speed displacement. Since modern elevators benefit of speed modeling, using electronic devices such as frequency convertors, this paper intents to explore the possibility of decelerating the cabin of an elevator smoothly, without using the constant speed step.

Speed control introduced the possibility of accelerating and decelerating the elevator using the so called S curves, consisting in two arches of curve and insuring a smooth variation of speed and acceleration, in order to increase comfort and avoid shocks. Various curves were used in order to generate S curves, such as polynomial

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and trigonometric ones.

Kinematic parameters of an elevators functioning cycle are speed, acceleration and its derivate, jerk. The time evolution of each parameter will be studied in this paper, 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.

2. THEORETICAL CONSIDERATIONS

An elevator's functioning cycle has three main time periods: accelerating time, the period of constant speed travel, and deceleration time. The last one is usually divided in three intervals: decelerating, constant speed step, and stop time, as shown in Figure 1. We explore the situation when deceleration is realized with continuous speed (Figure 2).

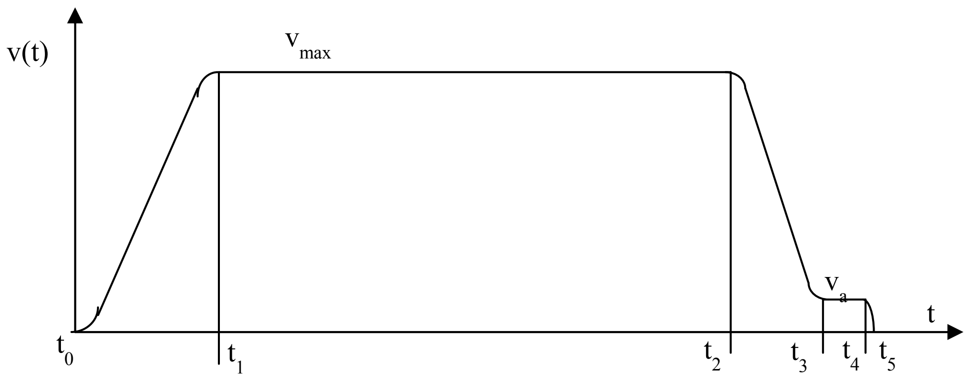


Fig. 1. Time periods of a functioning cycle for an elevator with constant speed step deceleration

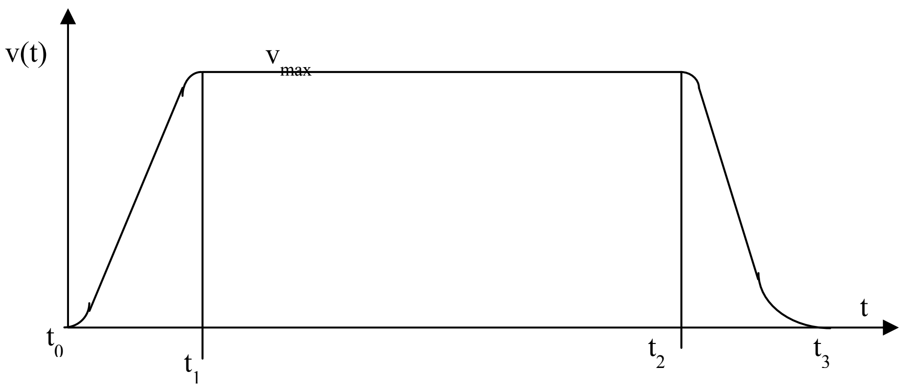


Fig. 2. Time periods of a functioning cycle for an elevator with continuous speed deceleration

In order to compare the time evolution of the parameters during the deceleration period of an elevator functioning cycle, with and without constant speed step, the same time duration will be maintained in both situations. After the elaboration of the time variation functions for jerk, acceleration and speed, diagrams were generated using MATLAB.

Mathematical modeling was based on an elevator for personnel, having 8 stations, traveling 22,4 meters, with the following values of the main kinematic parameters: maximum speed $v_{\max} = 1$m/s; peak values of acceleration at start and stop: $a_1 = a_2 = 0{,}8$ m/s^2; constant speed value at deceleration $v_a = 0{,}2$ m/s, constant speed step duration: 2s.

2.1. The study of the elevator's functioning cycle with parabolic variation of speed

Using time notations defined in Figure 1, for the cycle with decelerating step of continuous speed, the time variation of jerk, acceleration and speed are governed by the following equations:

Jerk variation:

$$\begin{cases} j_{01} = j_1 - \dfrac{2j_1}{t_1}t \\ j_{12} = 0 \\ j_{23} = -j_2 + \dfrac{2j_2}{t_3 - t_2}(t - t_2) \\ j_{34} = 0 \\ j_{45} = -j_3 + \dfrac{j_3}{t_5 - t_4}(t - t_4) \end{cases} \tag{1}$$

Acceleration variation:

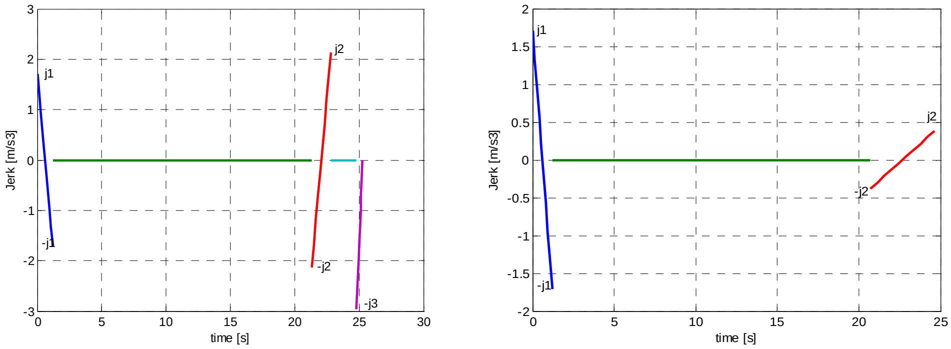
$$\begin{cases} a_{01} = j_1 t - \dfrac{j_1}{t_1}t^2 \\ a_{12} = 0 \\ a_{23} = -j_2(t - t_2) + \dfrac{j_2}{t_3 - t_2}(t - t_2)^2 \\ a_{34} = 0 \\ a_{45} = -j_3(t - t_4) + \dfrac{j_3}{t_5 - t_4}\dfrac{(t - t_4)^2}{2} \end{cases} \tag{2}$$

Speed variation:

$$\begin{cases} v_{01} = j_1 \dfrac{t^2}{2} - \dfrac{j_1}{t_1} \dfrac{t^3}{3} \\ v_{12} = v_{\max} \\ v_{23} = v_{\max} - j_2 \dfrac{(t-t_2)^2}{2} + \dfrac{j_2}{t_3 - t_2} \dfrac{(t-t_2)^3}{3} \\ v_{34} = v_a \\ v_{45} = v_a - j_3 \dfrac{(t-t_4)^2}{2} + \dfrac{j_3}{t_5 - t_4} \dfrac{(t-t_4)^3}{6} \end{cases} \quad (3)$$

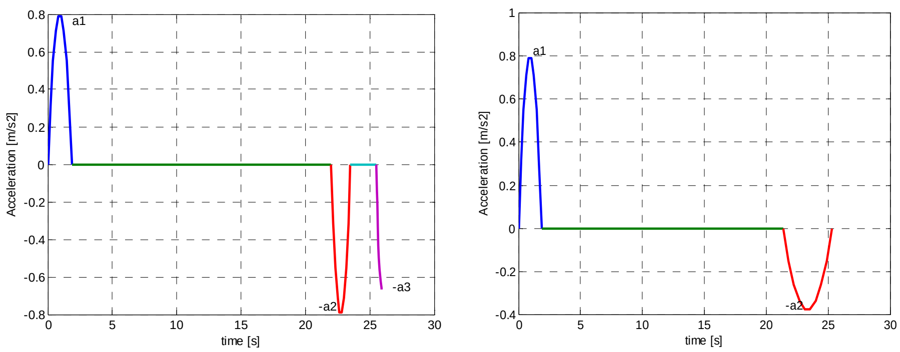
If speed variation has no longer the step of constant value at deceleration, the functioning cycle will no longer have five intervals, but only three, as shown in Figure 2, therefore the last two relations will be not necessary for every parameter.

The following diagrams were generated (Figures 3 to 5):



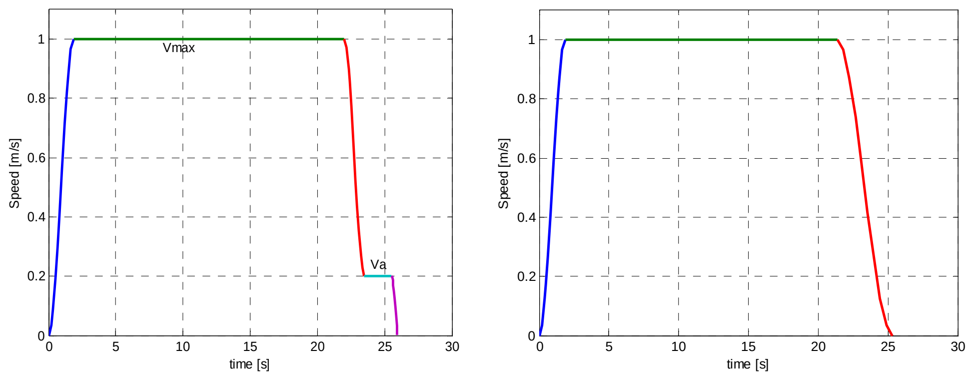
(a) (b)

Fig. 3. Variation of jerk in the case of parabolic speed modeling, with speed step (a) and with continuous speed (b)



(a) (b)

Fig. 4. Variation of acceleration in the case of parabolic speed modeling, with speed step (a) and with continuous speed (b)



(a) (b)

Fig. 5. Variation of speed in the case of parabolic speed modeling, with speed step (a) and with continuous speed (b)

Under the criteria of the same duration of deceleration period in the cases of deceleration with constant speed step and with continuous speed, as seen in Figures 3 and 4, the peak values of acceleration and jerk are significantly reduced if eliminating the constant speed step.

2.2. The study of the elevator's functioning cycle with cosinusoidal variation of speed

In order to generate the variation diagrams in both deceleration cases for an elevator with cosinusoidal speed modeling, the following equations were written, notations are according to Figures 1 and 2.

Jerk variation:

$$\begin{cases} j_{01}(t) = j_1 \sin \dfrac{2 j_1}{a_1} t \\ j_{12}(t) = 0 \\ j_{23}(t) = -j_2 \sin \dfrac{2 j_2}{a_2}(t - t_2) \\ j_{34}(t) = 0 \\ j_{45}(t) = -j_3 \sin \dfrac{2 j_3}{a_3}(t - t_4) \end{cases} \tag{4}$$

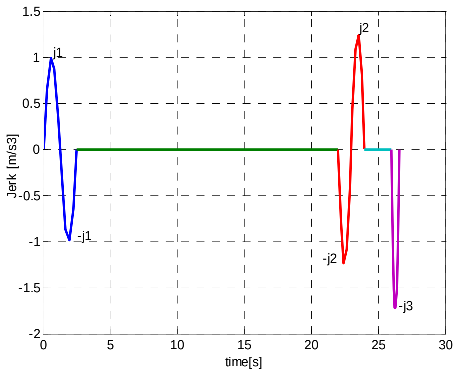
Acceleration variation:

$$\begin{cases} a_{01}(t) = \dfrac{a_1}{2}(1 - \cos\dfrac{2\,j_1}{a_1}t) \\ a_{12}(t) = 0 \\ a_{23}(t) = -\dfrac{a_2}{2}(1 - \cos\dfrac{2\,j_2}{a_2}(t - t_2)) \\ a_{34}(t) = 0 \\ a_{45}(t) = -\dfrac{a_3}{2}(1 - \cos\dfrac{2\,j_3}{a_3}(t - t_4)) \end{cases} \tag{5}$$

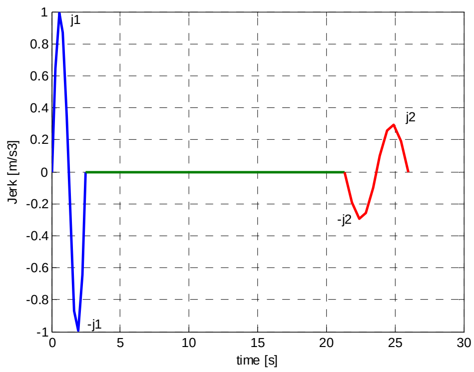
Speed variation:

$$\begin{cases} v_{01}(t) = \dfrac{a_1}{2}(t - \dfrac{a_1}{2\,j_1}\sin\dfrac{2\,j_1}{a_1}t) \\ v_{12}(t) = v_{max} \\ v_{23}(t) = v_{max} - \dfrac{a_2}{2}\left((t - t_2) - \dfrac{a_2}{2\,j_2}\sin\dfrac{2\,j_2}{a_2}(t - t_2)\right) \\ v_{34}(t) = v_a \\ v_{45}(t) = v_a - \dfrac{a_3}{2}\left((t - t_4) - \dfrac{a_3}{2\,j_3}\sin\dfrac{2\,j_3}{a_3}(t - t_4)\right) \end{cases} \tag{6}$$

The diagrams that show the time variation of parameters are shown in Figures 6 to 8.

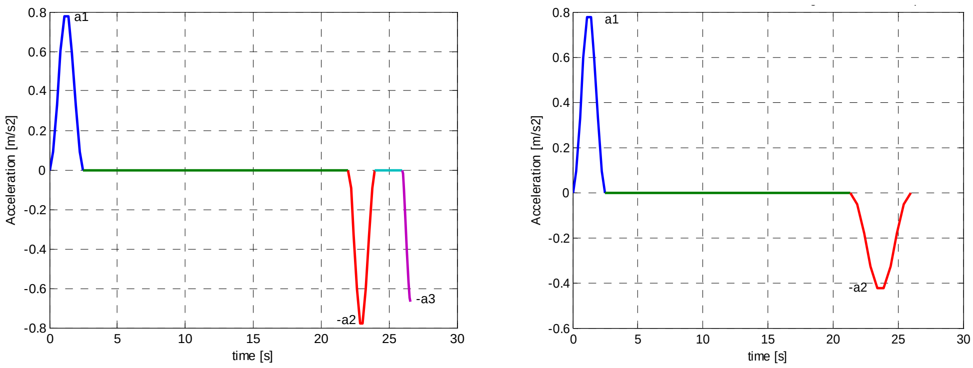


(a)



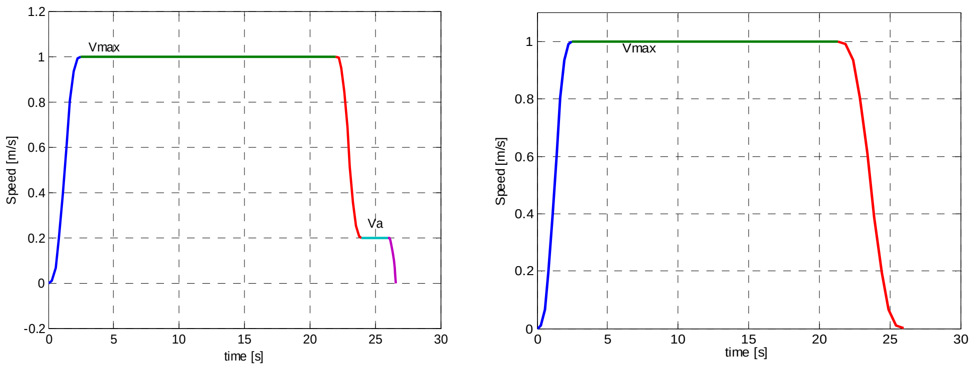
(b)

Fig. 6. Variation of jerk in the case of cosinusoidal speed modeling, with speed step (a) and with continuous speed (b)



(a) (b)

Fig. 7. Variation of acceleration in the case of cosinusoidal speed modeling, with speed step (a) and with continuous speed (b)



(a) (b)

Fig. 8. Variation of speed in the case of cosinusoidal speed modeling, with speed step (a) and with continuous speed (b)

3. INTERPRETATIONS AND CONCLUSIONS

Using MATLAB, the peak values of the main kinematic parameters and time durations were determined in both deceleration cases, for the two speed modeling varieties. The values are shown in Table 1.

Analyzing the values from the Table 1, we can observe that in both cases of speed modeling, decelerating with continuous speed reduces peak value of acceleration, as well as peak value of jerk.

Total duration of the functioning cycle is also reduced, in both cases of speed modeling.

Eliminating the constant speed step means fewer modifications of acceleration and jerk during deceleration period, resulting in more comfort for the passengers in the elevator's cabin.

A smoother variation of acceleration occurs in lesser values of the inertia forces in the entire system; hence the mechanical elements will be less stressed.

In order to insure precision at floor alignment of cabin, deceleration using an asymmetrical S curve may also be examined.

Table 1. *Kinematic parameters values for parabolic and cosinusoidal speed modeling, in cases of deceleration with speed step and with continuous speed*

	PARABOLIC with speed step	**PARABOLIC with continuous speed**	**COSINUSOIDAL with speed step**	**COSINUSOIDAL with continuous speed**
Δt_{total} [s] Δt_{acc} [s] $\Delta t_{ctspeed}$[s] Δt_{decel} [s]	25,9311 1,875 20,1063 3,95	25,3125 1,875 19,4875 3,95	26,5669 2,5 19,4671 4,6	25,9514 2,5 18,8514 4,6
j_1 [m/s^3] j_2 [m/s^3] j_3 [m/s^3]	1,7067 2,21333 2,9659	1,7067 1,3846	1,0053 1,2566 1,7471	1,0053 0,2969
a_1 [m/s^2] a_2 [m/s^2] a_3 [m/s^2]	0,8 0,8 0,6667	0,8 0,3797 -	0,8 0,8 0,6667	0,8 0,4348 -

Further examinations, in order to use continuous deceleration for elevators, will refer to the variation of dynamic parameters (power and energy), during a functioning cycle.

The influence of continuous variation of speed at deceleration on the oscillatory movements of the cabin's suspension cable may also be studied.

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