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**Ioana CRĂCIUN, Mioriţa UNGUREANU***

# ANALYSIS SHOCK TO START AND STOP AN ELEVATOR

# ANALÝZA NÁRAZŮ PŘI ROZJEZDU A ZASTAVENÍ VÝTAHU

**Abstract**

The paper studies the dynamics of an elevator, the theoretical determination of jerk at the start and stop of an elevator for a certain tachogram. *Maximum shock acceptable values are imposed by standards.*

**Abstrakt**

Článek se studuje dynamiku výtahem, teoretické stanovení nárazu na začátku a zastavení výtahu pro určitý tachogram. Maximální přípustné hodnoty nárazů jsou uvedeny v příslušných normách.

## 1 INTRODUCTION

Human transportation imposes a smooth functioning of elevators or any other devices used for this purpose, therefore the kinematical diagrams proposed for these systems must ensure certain values of the parameters, in order not to create any discomfort for passengers.

The functioning of an elevator is caracterized by certain kinematic and dynamic parameters, such as speed, acceleration and jerk, meaning the derivate of acceleration. The values of these parameters depend as much on technological factors as on the presence of man in the system. As shown in paper [2], the limits of the dynamical parameters that can be tolerated by human are:

Table 1. Recommended limits for kinematical parameters at personal transportation.

| Parameter | Limits |
|---|---|
| Vertical acceleration / deceleration | $\leq 1.0 – 1.5$ m/s$^2$ |
| Speed | $\leq 7$ m/s |
| Jerk rate | $\leq 2.5$ m/s$^3$ |
| Sound | $\leq 50$ dB |
| Ear pressure change | $\leq 2000$ Pa |

This paper aims to determinate for a real diagram of speed, the jerk rate and the relations between the kinematical parameters.

* Assist. Ioana CRĂCIUN , Prof. Mioriţa UNGUREANU, North University of Baia Mare, Department of Industrial Systems and Technological Management, Baia Mare, 430083, str. Dr. Victor Babeş, Nr. 62/A, Romania, Phone: +40 262 218922, Fax: +40 262 276153, E-mail: ioanacraciun2008@yahoo.com, web: http://www.ubm.ro

## 2 METHODS AND PRINCIPLES

In order to get a smooth passage from one phase to another during acceleration and deceleration periods, the theoretical linear variation of speed should be replaced by other variations, such as parabolic, co sinusoidal, or a third degree parabola.

Considering the theoretical speed diagram with parabolic variation of speed during acceleration and deceleration periods, due to a linear triangular variation of acceleration, (Fig.1) the following diagrams for acceleration and jerk can be determined. The triangular form of acceleration is a consequence of short periods of acceleration and deceleration.

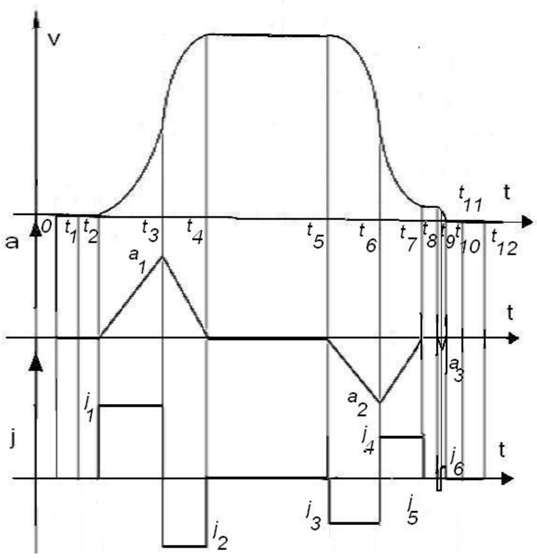


**Fig. 1.** Tachogram with parabolic variation of speed and linear triangular variation of acceleration.

The following variation result from the diagrams:

$$j(t)=\begin{cases} 0 & t\in(0,t_2) \\ j_1 & t\in[t_2,t_3] \\ -j_2 & t\in[t_3,t_4] \\ 0 & t\in(t_4,t_5) \\ -j_3 & t\in[t_5,t_6] \\ j_4 & t\in[t_6,t_7] \\ 0 & t\in(t_7,t_8) \\ -j_5 & t\in[t_8,t_9] \\ j_6 & t\in[t_9,t_{10}] \\ 0 & t\in(t_{10},t_{12}) \end{cases} \quad \text{for} \qquad (2.1)$$

Since the value of acceleration at $t_2$, $t_4$, $t_5$, $t_7$, $t_8$ and $t_{10}$ is 0, the following relations between jerk rates and time can be written:

$$\begin{cases} j_1(t_3 - t_2) = -j_2(t_4 - t_3) \\ -j_3(t_6 - t_5) = j_4(t_7 - t_6) \\ -j_5(t_9 - t_8) = j_6(t_{10} - t_9) \end{cases} \tag{2.2}$$

So we can write:

$$\begin{cases} j_2 = \dfrac{-j_1(t_3 - t_2)}{t_4 - t_3} \\ j_4 = \dfrac{-j_3(t_6 - t_5)}{t_7 - t_6} \\ j_6 = \dfrac{-j_5(t_9 - t_8)}{t_{10} - t_{11}} \end{cases} \tag{2.3}$$

The acceleration varies as follows:

$$a(t) = \begin{cases} 0 \\ j_1(t - t_2) \\ j_1 \dfrac{t_3 - t_2}{t_3 - t_4}(t - t_4) \\ 0 \\ -j_3(t - t_5) \\ -j_3 \dfrac{t_6 - t_5}{t_6 - t_7}(t - t_7) \\ 0 \\ -j_5(t - t_8) \\ -j_5 \dfrac{t_9 - t_8}{t_9 - t_{10}}(t - t_{10}) \\ 0 \end{cases} \quad \text{for} \quad \begin{matrix} t \in (0, t_2) \\ t \in [t_2, t_3] \\ t \in [t_3, t_4] \\ t \in (t_4, t_5) \\ t \in [t_5, t_6] \\ t \in [t_6, t_7] \\ t \in (t_7, t_8) \\ t \in [t_8, t_9] \\ t \in [t_9, t_{10}] \\ t \in (t_{10}, t_{12}) \end{matrix} \tag{2.4}$$

Since speed value is 0 at times $t_2$ and $t_9$, the following relations result from the diagram:

$$j_1 \frac{(t_3 - t_2)^2}{2} + j_1 \frac{(t_3 - t_2)(t_4 - t_3)}{2} = j_3 \frac{(t_6 - t_5)^2}{2} + j_3 \frac{(t_6 - t_5)(t_7 - t_6)}{2} + \\ + j_5 \frac{(t_9 - t_8)^2}{2} + j_5 \frac{(t_9 - t_8)\ (t_{10} - t_9)}{2} \tag{2.5}$$

This conducts to:

$$j_1 \frac{(t_3 - t_2)(t_4 - t_2)}{2} = j_3 \frac{(t_6 - t_5)(t_7 - t_5)}{2} + j_5 \frac{(t_9 - t_8)(t_{10} - t_8)}{2}$$

Speed values will be calculated as:

$$\bar{v}(t)=\begin{cases}0\\ j_1\dfrac{(t-t_2)^2}{2}\\ j_1\dfrac{(t_3-t_2)^2}{2}+j_1\dfrac{t_3-t_2}{t_3-t_4}\left(\dfrac{t^2}{2}-\dfrac{t_3^2}{2}-t_4(t-t_3)\right)\\ v_{max}=\dfrac{1}{2}j_1(t_3-t_2)(t_4-t_2)\\ \dfrac{j_1(t_3-t_2)(t_4-t_2)}{2}-\dfrac{j_3(t-t_5)^2}{2}\\ \dfrac{j_1(t_3-t_2)(t_4-t_2)}{2}-\dfrac{j_3(t_6-t_5)^2}{2}-\dfrac{j_3(t_6-t_5)}{t_6-t_7}\left(\dfrac{t^2}{2}-\dfrac{t_6^2}{2}-t_7(t-t_6)\right)\\ v_7=\dfrac{j_1(t_3-t_2)(t_4-t_2)}{2}-\dfrac{j_3(t_6-t_5)(t_7-t_5)}{2}\\ v_7-j_5(t-t_8)\\ v_7-j_5(t_8-t_9)-\dfrac{j_5(t_8-t_9)}{t_9-t_{10}}\left(\dfrac{t^2}{2}-\dfrac{t_{10}^2}{2}-t_{10}(t-t_9)\right)\\ 0\end{cases} \tag{2.6}$$

For an elevator having $a_1$ = 1 m/s$^2$, $v_{max}$ = 1 m/s, and acceleration time $t_4 - t_2$ = 1s, we get from relation (2.6):

$$v_{max}=\frac{1}{2}j_1(t_3-t_2)(t_4-t_2) \iff 1=\frac{1}{2}j_1(t_3-t_2)\cdot 1 . \tag{2.7}$$

If we consider symetrical the acceleration diagram for interval $t_2 - t_4$ , meaning $t_3 - t_2$ = 0,5 s , we obtain: $1=\frac{1}{2}j_1\cdot 0.5\cdot 1$ , and $j_1$ = 4 m/s$^3$, wich is much higher than the maximum admited value. In conclusion, times $t_3 - t_2$ and $t_4 - t_3$ cannot be equal, wich consists with the actual functioning of the AC machine. Considering maximum value $j_1$ = 2.5 m/s$^3$, relation (2.7) becomes:

$$1=\frac{1}{2}\cdot 2.5\cdot(t_3-t_2)\cdot 1 \tag{2.8}$$

which conducts to the value $t_3 - t_2$ = 0.8 s, and $t_4 - t_3$ = 0,2 s, meaning $t_3 - t_2 = 4(t_4 - t_3)$.

With these values, we can determine $j_2$ as

$$j_2=\frac{-j_1(t_3-t_2)}{t_4-t_3}=\frac{2{,}5\cdot 0{,}8}{1}=2m/s^3 \tag{2.9}.$$

Obviously, values $j_3$, $j_4$, $j_5$ and $j_6$ are considerably lower than $j_1$ and $j_2$.

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[5] *** *Directive 95/16/EC relating to Elevators*