ABOUT POWER AND ENERGY ABSORPTION AT ELEVATORS WITH SPEED MODELING

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ABSTRACT: Energy and power absorption is a permanent subject of improvement in elevator technologie. Speed control technologie for electric traction elevators allowes to investigate several modeling posibilities. The paper aims to compare three modeling variants: trapezoidal modeling, parabolic modeling and cosinusoidal modeling of acceleration, if lifting the fully loaded and the empty cabin of a personnel elevator. Three comparison criteria were propsed: maintainig the same acceleration, mantaining the same time duration, and limiting jerk.
KEY WORDS: speed modelling, lift acceleration, power, energy.

1 INTRODUCTION

In the actual context of the global warming, saving energy is an important goal for all the industries. Electric traction elevators are also a subject of improvements, from the point of view of power and energy consumption.

As shown in paper *Energy Efficient Elevator Technologies*, in energy-efficient elevator technology, regenerative drives are a remarkable advancement. They recycle energy rather than wasting it as heat.

When lifting the empty elevator cabin and descending it heavily loaded, the system generates more power than it uses. If these small amounts of power are recycled, they add up to significant savings.

Considering that we desire a swift, but safe movement, due to the presence of man, it's been imposed a strict limitation of the peak values of speed, acceleration and jerk following an experimental evaluation of the supportable limits of these parameters. The solutions of these issues had evolved together with the elevators technology progress. In time, there were developed models that propose controlled variations of acceleration, in order to limit jerk values during transportation.

This paper aims to evaluate from the point of view of power absorption at lifting the fully loaded and the empty cabin of an electrical traction elevator with speed modeling, considering three cases:

- trapezoidal variation of acceleration
- parabolic variation of acceleration
- cosinusoidal variation of acceleration.

2 THEORETICAL CONSIDERATIONS

From the point of view of its dynamics, the system cabin – friction wheel – counterweight represents a system of rigid bodies with a single degree of freedom, as long as we ignore the motions due to the elasticity of the traction cable.

Starting from the general dynamic equation of an elevator reduced at the edge of the friction wheel, we write the expressions of the time variation of power during a cycle, in all three acceleration modelling variants.

In the hypothesis of coulombian friction with constant coefficient, the diagrams of power time variation were generated, using program MATLAB, considering the lift of the fully loaded cabin and of the empty cabin.

Also, using the kinematic equations for the three models, the energy absorption has been evaluated.

Since the most significant energy absorption occurs at the acceleration of the system when lifting the cabin, the paper refers only to this part of the functioning cycle of the elevator.

In order to better highlighting the differences, three cases of comparison were considered:

- case a): maintaining of the same value of acceleration;

- case b): maintaining the same duration of accelerating period;

- case c): limiting jerk during acceleration period.

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Beginning from the dynamic equation of an elevator,

$$F_m = F_{st} + F_d + F_{fr} \qquad (1)$$

in which F is the driving force, F_{st} represents the static forces, (mainly weights), F_d represents the dynamic forces, occurring only during acceleration and deceleration periods, and F_{fr} are the resistant forces, (mainly friction forces) for the three modelling situations, the following equations were written:

1) Trapezoidal variation of acceleration:

Power variation:

For $t \in (0, t_1)$

$$P_{01} = (F_{st} + F_{fr}) \cdot v_{01}(t) + \sum m \cdot a_{01}(t) \cdot v_{01}(t) = (F_{st} + F_{fr}) \cdot j_1 \frac{t^2}{2} + \sum m \cdot j_1{}^2 \frac{t^3}{2} \qquad (2)$$

For $t \in (t_1, t_2)$

$$P_{12} = (F_{st} + F_{fr}) \cdot v_{12}(t) + \sum m \cdot a_{12}(t) \cdot v_{12}(t) = (F_{st} + F_{fr}) \cdot [v_{01}(t_1) + a_1(t - t_1)] + \sum m \cdot [v_{01}(t_1) + a_1(t - t_1)] \cdot a_1 \qquad (3)$$

For $t \in (t_2, t_3)$

$$P_{23} = (F_{st} + F_{fr}) \cdot v_{23}(t) + \sum m \cdot a_{23}(t) \cdot v_{23}(t) = (F_{st} + F_{fr}) \cdot [v_{12}(t_2) + a_1(t - t_2) - j_2 \frac{(t - t_2)^2}{2}] + \sum m \cdot [v_{12}(t_2) + a_1(t - t_2) - j_2 \frac{(t - t_2)^2}{2}] \cdot [a_1 - j_2(t - t_2)] \qquad (4)$$

Energy variation:

For $t \in (0, t_1)$

$$E_{01} = \int_0^{t_1} P_{01} dt = (F_{st} + F_{fr}) \frac{j_1}{6} t_1^3 + \sum m \frac{j_1}{8} t_1^4 \qquad (5)$$

For $t \in (t_1, t_2)$

$$E_{12} = \int_{t_1}^{t_2} P_{12} dt = \left[(F_{st} + F_{fr}) + a_1 \cdot \sum m \right] \left[v_{01}(t_1)(t_2 - t_1) + \frac{a_1}{2}(t_2 - t_1)^2 \right] \qquad (6)$$

For $t \in (t_2, t_3)$

$$E_{23} = \int_{t_2}^{t_3} P_{23} dt = (F_{st} + F_{fr}) \left[v_{12}(t_2)(t_3 - t_2) + \frac{a_1}{2}(t_3 - t_2)^2 - \frac{j_2}{6}(t_3 - t_2)^3 \right] + \sum m \left[v_{12}(t_2) \cdot a_1 \cdot (t_3 - t_2) + \frac{\left(a_1^2 - j_2 v_{12}(t_2)\right)}{2}(t_3 - t_2)^2 \right] - \sum m \left[\frac{a_1 j_2}{2}(t_3 - t_2)^3 + \frac{j_2^2}{8}(t_3 - t_2)^4 \right] \qquad (7)$$

2) Parabolic variation of acceleration:

Power variation:

For $t \in (0, t_1)$

$$P_{01} = (F_{st} + F_{fr}) \cdot v_{01}(t) + \sum m \cdot a_{01}(t) \cdot v_{01}(t) = (F_{st} + F_{fr}) \cdot \left(j_1 \frac{t^2}{2} - \frac{j_1}{t_1} \frac{t^3}{3} \right) + \sum m \cdot \left(j_1 \frac{t^2}{2} - \frac{j_1}{t_1} \frac{t^3}{3} \right) \cdot \left(j_1 t - \frac{j_1}{t_1} t^2 \right) \qquad (8)$$

Energy variation:

For $t \in (0, t_1)$

$$E_{01} = \int_0^{t_1} P_{01} dt = (F_{st} + F_{fr}) \cdot \left(\frac{j_1}{6} t_1^3 - \frac{j_1}{12 t_1} t_1^4 \right) + \sum m \cdot \left(\frac{j_1^2}{18 t_1^2} t_1^6 - \frac{5 j_1^2}{30 t_1} t_1^5 + \frac{j_1^2}{8} t_1^4 \right) \qquad (9)$$

3) Cosinusoidal variation of acceleration:

Power variation:

For $t \in (0, t_1)$

$$P_{01} = (F_{st} + F_{fr}) \cdot v_{01}(t) + \sum m \cdot a_{01}(t) \cdot v_{01}(t) = (F_{st} + F_{fr}) \cdot \left(\frac{a_1}{2}(t - \frac{a_1}{2 j_1} \sin \frac{2 j_1}{a_1} t) \right) + \sum m \cdot \left(\frac{a_1}{2}(t - \frac{a_1}{2 j_1} \sin \frac{2 j_1}{a_1} t) \right) \cdot \left(\frac{a_1}{2}(1 - \cos \frac{2 j_1}{a_1} t) \right) = (F_{st} + F_{fr}) \cdot \left(\frac{a_1}{2}(t - \frac{t_1}{2\pi} \sin \frac{2\pi}{t_1} t) \right) + \sum m \cdot \left(\frac{a_1}{2}(t - \frac{t_1}{2\pi} \sin \frac{2\pi}{t_1} t) \right) \cdot \left(\frac{a_1}{2}(1 - \cos \frac{2\pi}{t_1} t) \right) \qquad (10)$$

Energy variation:

For $t \in (0, t_1)$

$$E_{01} = \int_0^{t_1} P_{01} dt = \left(F_{st} + F_{fr}\right) \cdot \frac{a_1}{2}\left(\frac{t_1^2}{2} + \frac{a_1^2}{4 j_1^2}\cos\frac{2 j_1}{a_1} t_1\right) +$$

$$+\sum m \frac{a_1^2}{4}\left(\frac{t_1^2}{2} - \frac{a_1 t_1}{2 j_1}\sin\frac{2 j_1}{a_1} t_1 - \frac{a_1^2}{16 j_1^2}\cos\frac{4 j_1}{a_1} t_1\right) \quad (11)$$

Considering a personnel elevator serving 8 stations, with the parameters in described in Table 1, the equations above conducted to the following diagrams, generated in MATLAB.

Table 1.Kinematic and dynamic parameter values

Maximum speed	**Vmax =1 m/s**
case a) maintaining acceleration value	
Acceleration	a1 = 0.8 m/s^2
case b) maintaining time duration	
Accelerating time	t1 = 2.4 s
Case c) limited jerk – values of acceleration	
trapezoidal:	a1=0.8
parabolic:	a1=0.7
cosinusoidal:	a1=0.8
Nominal power of engine	Pm= 5.5CV = 4 kW
Cabin weight	GC = 6280 N
Counterweight	GCG =7780 N
Payload	Gu = 3000 N
Normal reaction forces on rails	
cabin	Sx=205 N
	Sy =223 N
counterweight	Sx = 20 N
	Sy = 158 N
Static friction coefficient	μ_{st} = 0.15
Maximum height of rise	Hmax=22.4 m

2.1 Power variation and energy absorption, considering the three variants of speed modeling, and the three cases of comparison

2.1.1 Power variation and energy absorption considering the same values of acceleration

Accelerating the elevator with the same acceleration rate, both jerk and time duration will be different from one model to another, therefor power variation will differ too, as shown in Figure 1.

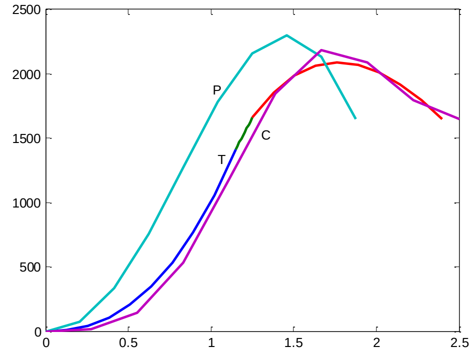

Figure 1. Power variation at lifting the fully loaded elevator cabin, acceleration period, maintaining the same values of acceleration

P – parabolic variation of acceleration
T – trapezoidal variation of acceleration
C – cosinusoidal variation of acceleration

Power variation occurs in different values of the energy absorbed during acceleration period (Figure 2)

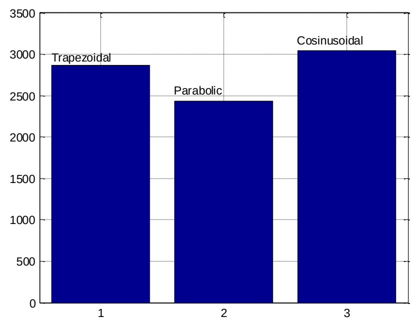

Figure 2. Energy absorption at lifting the fully loaded elevator cabin, acceleration period, maintaining the same values of acceleration

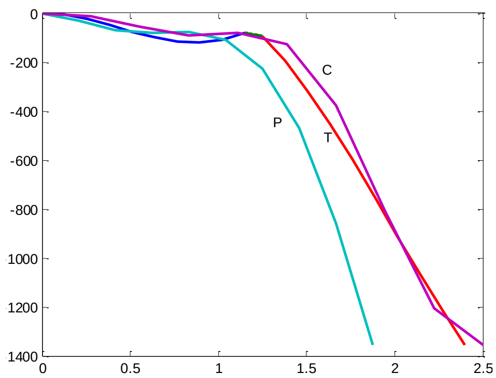

Figure 3. Power variation at lifting the empty elevator cabin, acceleration period, maintaining the same values of acceleration

P – parabolic variation of acceleration
T – trapezoidal variation of acceleration
C – cosinusoidal variation of acceleration

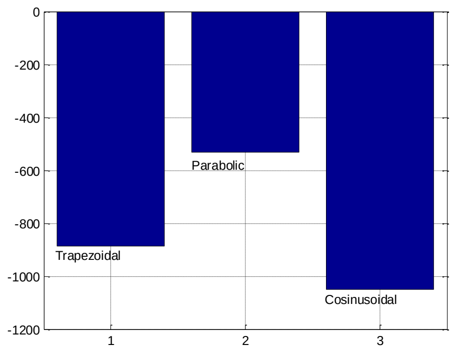

Figure 4. Energy variation at lifting the empty elevator cabin, acceleration period, maintaining the same values of acceleration

At lifting the fully load cabin with the same acceleration rate, the highest value of power is reached if using de parabolic modeling. Although the energy absorption is the lowest, this happens because of the shorter time duration. Also, if lifting the empty cabin, the parabolic model allows the less energy saving, if using a regenerative drive.

2.1.2 Power variation and energy absorption considering the same durations of accelerating period

Lifting the cabin with the same time duration using the three models of acceleration reduces both acceleration rate and jerk for the parabolic model, increasing the rates of these parameters for the cosinusoidal model.

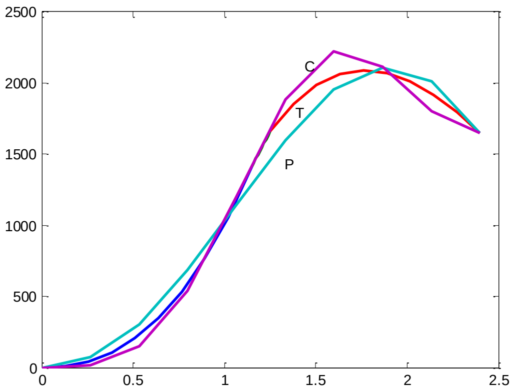

Figure 5. Power variation at lifting the fully loaded elevator cabin, acceleration period, maintaining the same time duration

P – parabolic variation of acceleration
T – trapezoidal variation of acceleration
C – cosinusoidal variation of acceleration

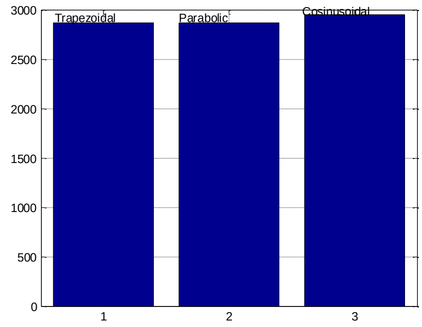

Figure 6. Energy absorption at lifting the fully loaded elevator cabin, acceleration period, maintaining the same time duration

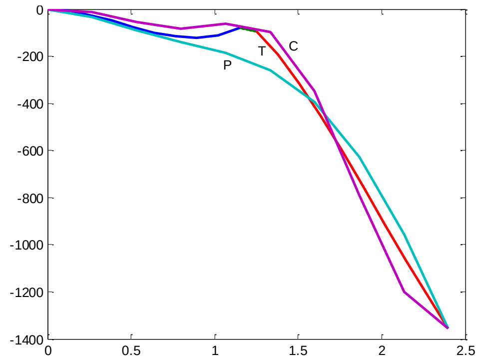

Figure 7. Power variation at lifting the empty elevator cabin, acceleration period, maintaining the same time duration

P – parabolic variation of acceleration
T – trapezoidal variation of acceleration
C – cosinusoidal variation of acceleration

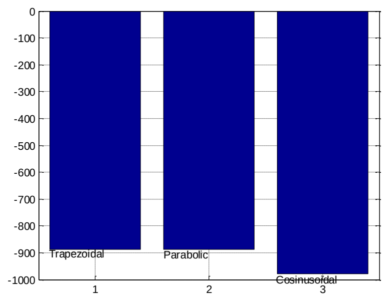

Figure 8. Energy variation at lifting the empty elevator cabin, acceleration period, maintaining the same time duration

Under the criteria of the same time duration, the peak value of power will be the lowest if using the parabolic modeling of acceleration, while the cosinusoidal model will produce the highest peak value. Energy saving is still higher if using the cosinusoidal modeling, as it was under the previous criteria.

2.1.3 Power variation and energy absorption at limited jerk

Since both previous criteria conduced at high values of jerk, mainly in the case of parabolic modeling, it's been introduced the jerk limitation. Values of acceleration rate and time duration were both modified under this request, as seen in Table 1.

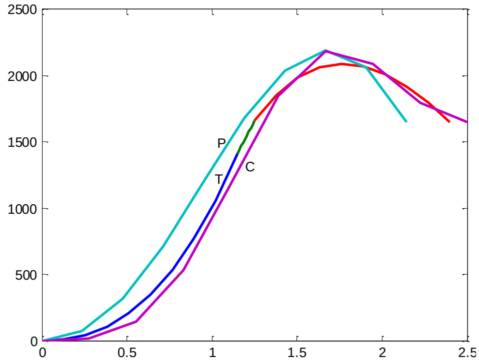

Figure 9. Power variation at lifting the fully loaded elevator cabin, acceleration period at limited jerk

P – parabolic variation of acceleration
T – trapezoidal variation of acceleration
C – cosinusoidal variation of acceleration

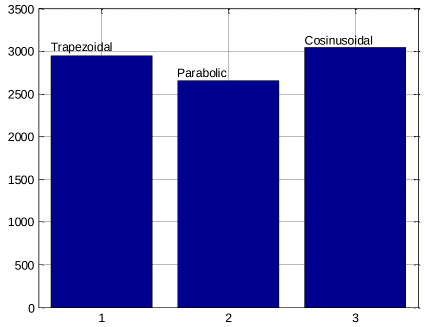

Figure 10. Energy variation at lifting the fully loaded elevator cabin, acceleration period, at limited jerk

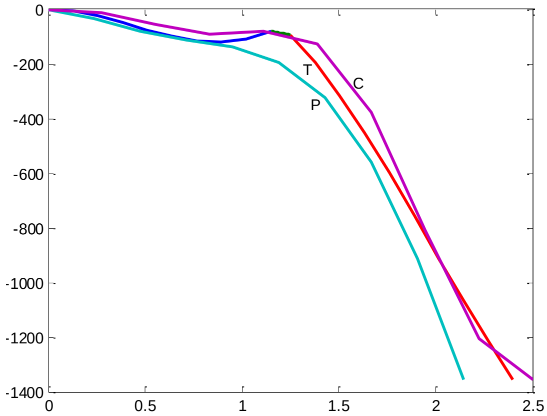

Figure 11. Power variation at lifting the empty elevator cabin, acceleration period, at limited jerk

P – parabolic variation of acceleration
T – trapezoidal variation of acceleration
C – cosinusoidal variation of acceleration

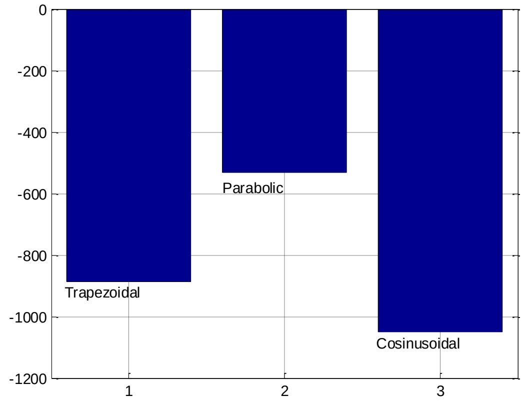

Figure 12. Energy variation at lifting the empty elevator cabin, acceleration period, at limited jerk

At limited jerk, peak values of power when lifting the fully loaded cabin will be the same in the cases of parabolic and cosinusoidal modeling. Although, cosinusoidal modeling allows saving more energy.

3 CONCLUDING REMARKS

At lifting the fully loaded cabin, under the three criteria that have been formulated, the cosinusoidal modeling of acceleration has shown the steadiest behaviour, in terms of acceleration rate, jerk and time duration. Power variation and energy absorption were sensibly equal in the three cases. The parabolic modeling of acceleration reduces the accelerating time, even at limited jerk.

In terms of energy absorption, an evaluation of it for an entire functioning cycle is required, since the total distance of a ride has a high influence on the energy amount.

4 REFERENCES

►Bratu, P., Gillich, G.R., (2006) *Reference Values in Evaluating Effects of Vibrations on Buildings and Persons*, Annals of "Eftimie Murgu" University Reşiţa, anul XIII NR. 1, pp. 111 - 116, , ISSN 1453 – 73972006

► Chen, Y., Wei H., Sun, K., Liu, M., Wang, T., (2011) *Algorithm for smooth S-curve Feedrate Profiling Generation*, Chinese Journal of Mechanical Engineering, vol. 24, No.*, pp. 1 – 11

►Sniderman, D.,(2012) Energy Efficient Elevator Technologies, available at:

►https://www.asme.org/engineering-topics/articles/elevators/energy-efficient-elevator-technologies, Accessed: 2014-09-15

5 NOTATION

The following symbols are used in this paper:
a1 = Start acceleration [m/s2];
F_m = Driving force [N];
F_{fr} = Resistant forces, mainly friction forces [N];
F_{st} = Static forces, mainly weights [N];
j1 = Jerk at start [m/s^3];
$P_{i,i+1}$ = Power for period (ti, ti+1) [W];
Sx , Sy = Normal reaction forces on rails [N];
(ti, ti+1) = Time duration of a period [s];
v_{max} = Maximum speed [m/s];
μ_{st} = Static friction coefficient [-];
$\sum m$ = Sum of moving masses, reduced at the edge of the friction wheel [kg].