



DESIGN OF ELEVATOR DRIVE WITH JERK CONTROL

Bojan Knežević, Branko Blanuša*, Darko Marčetić**

University of Banja Luka, Faculty of Mechanical Engineering, Banja Luka, B&H

*University of Banja Luka, Faculty of Electrical Engineering, Banja Luka, B&H

**University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Serbia

Abstract: Uncontrolled, the jerk have influence on the electrical and mechanical subsystem performance and reduce the system life expectance. Modern drives have ability to control speed, so we can indirectly control the jerk. This paper describes the control of real gear-less electric elevator drive with vector-controlled Permanent Magnet Synchronous Motor (PMSM). Position trajectory is determined by the need that jerk is changed by the predefined function. A mathematical model of the drive is presented, and it is tested through computer simulations.

Key Words: Elevator/Jerk control/Vector control

1. INTRODUCTION

The most common solution for vertical transport of passengers and goods in the residential and commercial buildings is an electrical elevator. Its construction is not substantially changed since the time when designed the first commercial elevators of this type. Control structures, safety elements, drive endurance and its durability and economy are constantly improved. Modern passenger elevators request high transport speed, low jerk, precise positioning, simple and efficient control and small number of sensors [1], [2], [3]. Particularly interesting in modern elevators is the comfort and convenience of passengers. Today there are elevators which reach the nominal speed of 18m/s in order to increase their availability in high office buildings with a high frequency of traffic. In these elevators there is a strong jerk, when they starting and stopping, which can cause discomfort of the passengers. Modern control drives can realize movement of the elevator with controlled jerk, so the idea of this work is very relevant and justified, especially when the effect of jerk in the projects of elevators are not usually analyzed.

Organization of paper is as follows:

Mathematical model of position trajectory which include jerk control is presented in second section. Description of system configuration, elevator with drives and drive sheave is presented in third section. Position control of drive is described in fourth section. Qualitative analyses of described model with simulation results are given in fifth section. Obtain results are summarized in conclusions.

2. MATHEMATICAL MODELING OF POSITION TRAJECTORY WITH JERK CONTROL

Jerk is defined as first derivation of acceleration. So, if the acceleration have step form, it causes a big jerks which have a negative effect to passengers and on the mechanical system of elevator. Also, the accuracy of the positioning is reduced and the overshoot and settling time increase. This is the case with the frequently used trapezoidal form of speed. For this shape of speed, acceleration has step form. Significant improvement can be achieved if the acceleration changes following the smooth curve. This provides less jerks and eliminate their harmful effects [4].

A case when the jerk in the process of acceleration and deceleration has the sinus function is suggested (Fig. 1):

$$j = \begin{cases} j_m \sin \frac{2\pi}{T} t, & t \in [0, T] \\ 0, & t \in [T, t_2] \\ -j_m \sin \frac{2\pi}{T} (t - t_2), & t \in [t_2, t_3] \end{cases} \quad (1)$$

where t_3 is total duration of movement, T is a time of acceleration/deceleration, $t_2 = t_3 - T$ is a moment when the object starts deceleration and j_m the maximum amplitude of jerk.

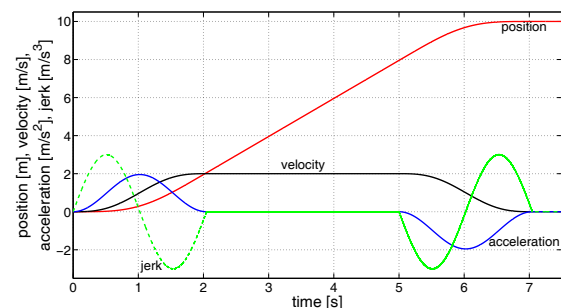


Fig. 5. Reference of jerk, acceleration, velocity and position.

Based on (1) the acceleration in particular intervals can be expressed by the following relation $a = \int j dt + C_a$, velocity as $v = \int a dt + C_v$ and the

displacement as $d = \int v dt + C_d$. From those relations we obtain that the displacement d , for every time interval, is (Fig. 1):

$$d = \begin{cases} j_m \frac{T}{4\pi} t^2 - j_m \frac{T^3}{8\pi^3} \left(1 - \cos \frac{2\pi}{T} t\right), & t \in [0, T] \\ j_m \frac{T^2}{4\pi} (2t - T), & t \in [T, t_2] \\ j_m \frac{T^2}{4\pi} \left[(2t - T) - \frac{(t - t_2)^2}{T} + \frac{T}{2\pi^2} \left[1 - \cos \frac{2\pi}{T} (t - t_2)\right] \right], & t \in [t_2, t_3] \end{cases} \quad (2)$$

Constants C_a , C_v and C_d are determined from initial conditions. The changes of j , a , v and d are presented graphically in Fig. 1.

The total displacement can be determined from (2) when $t=t_3$ as:

$$d(t_3) = d_m = j_m \frac{T^2}{2\pi} t_2. \quad (3)$$

Maximum value of displacements d_m and velocity V_m are known, so times T and t_2 are:

$$T = \sqrt{\frac{2\pi \cdot V_m}{j_m}}, \quad (4)$$

$$t_2 = \frac{2\pi \cdot d_m}{T^2 j_m}. \quad (5)$$

If the condition $t_3 > 2T$ (or $t_2 > T$) is not satisfied velocity V_m has to be reduced.

3. DESCRIPTION OF THE SYSTEM CONFIGURATION

The analyzed elevator considers electrical drive and drive sheave that is mounted directly to the motor shaft without gear.

Block diagram of the system is shown in Fig. 2. Drive makes Permanent Magnet Synchronous Motor (PMSM) with a drive converter, rectifier, DC link and current controlled PWM voltage inverter. Indirect vector control (IVC) is used for control of drive.

Where speed of rotational d,q system is equal to rotor speed and Ψ_f is a part of permanent magnet flux which participate in stator flux formation. Flux Ψ_f lies on d axis. Drive converter is current regulated PWM voltage inverter (CRPWM VSI).

Rotational movement of the motor shaft turns into linear movement over drive sheave directly mounted to motor shaft without gear box. The drive torque is transferred from the drive sheave by friction to the hoisting ropes that are connected to the car as counterweight. Drive sheave rotational speed is the same as rotational speed of motor shaft. Rotational and linear speed of car are related over radius of drive sheave. Load torque in the function of weight in the car can be calculated following the next expression:

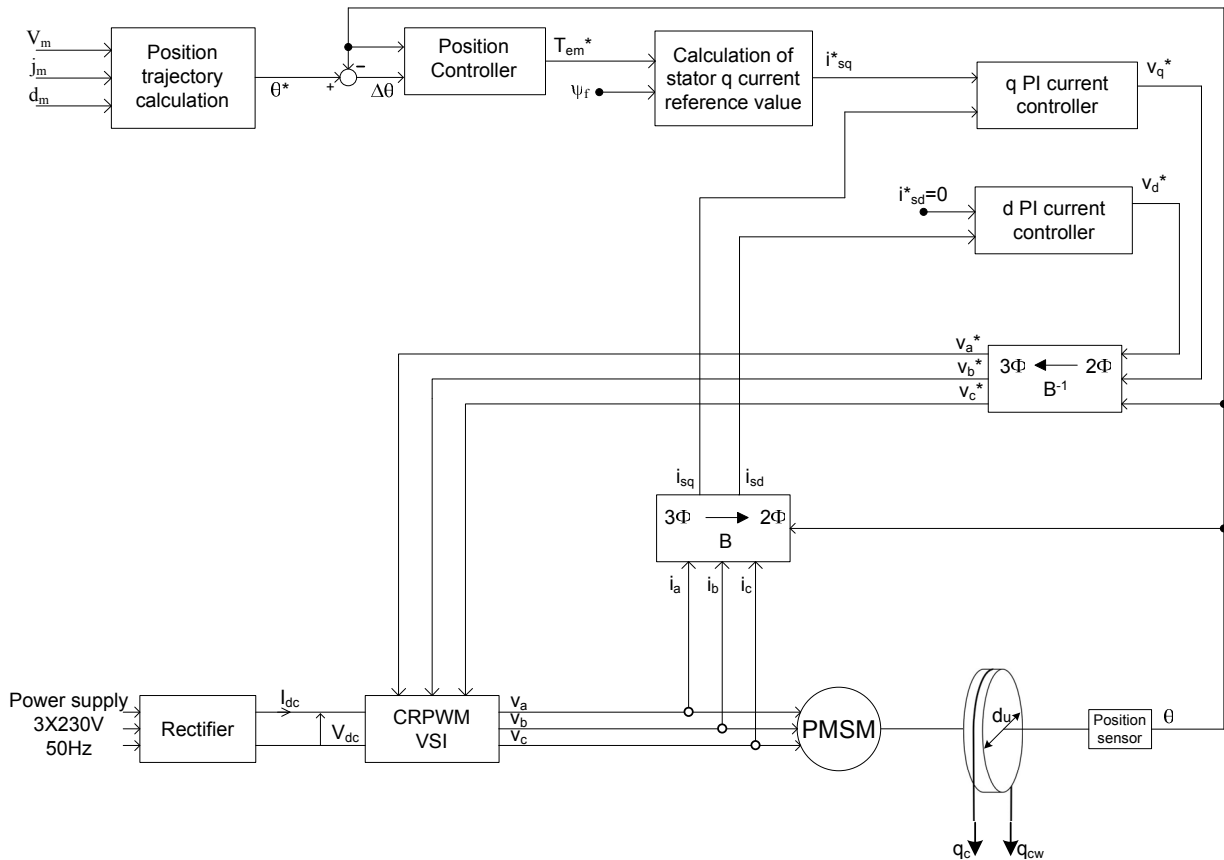


Fig. 2. Block diagram of the elevator system with vector controlled permanent magnet synchronous motor and drive sheave that is mounted directly to the motor shaft without gear.

$$m_{opt} = \frac{d_u}{2} g \left(q - \frac{q_m}{2} \right), \quad (6)$$

where d_u [m] is diameter of sheave, q [kg] is a weight in car and q_m [kg] is elevator capacity. The total inertia is calculated as:

$$J_m = J_r + \left(2q_c + q + \frac{q_m}{2} \right) \left(\frac{d_u}{2} \right)^2, \quad (7)$$

where J_r is inertia of rotating masses (rotor, brake, sheave, etc.) and q_c [kg] is a weight of car.

Position sensor is mounted on the motor and serves to achieve the position feedback.

4. DESIGN OF POSITION CONTROLLER

Elevator is the positioning system and position controller is used for the task to provide position reference tracking and zero error in steady state. To solve the problem of trajectory tracking application in elevators different types of position controllers are implemented, neural networks PID [5], variable structure control (VSC) [6], nonlinear control, etc. Constant load is usual for an elevator. So, a position controller with proportional, derivative and integral action (PID) is can be used (Fig. 3). It also provides the system with the capability of tracking the constant ramp profile without an error.

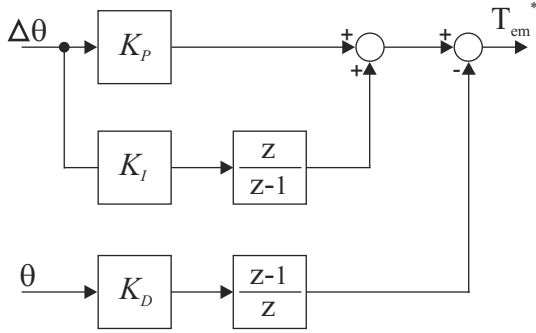


Fig. 3. Position controller.

Positioning controller synthesis is carried out for the load with modeled inertia (7). In the case of gearless elevator drive, which is the subject of interest in this paper, the drive motor is running at low revolutions. Therefore, a member in a transfer function of load, who depends of the speed, can be ignored. Kinetic and static (Coulomb's) friction is modeled as a disturbance. Kinetic friction is modeled with step function and the static friction is modeled with pulse whose duration is short at startup.

Usually, input disturbances are small, PID controller operates in linear mode and system limits ω_{max} (maximum angular speed) and T_{emax} are not reached. In a case when $\Delta\theta \geq \Delta\theta_{max}$ or $\omega \geq \omega_{max}$ torque and/or speed reaches the limits and the system operates in nonlinear mode. So, it is necessary to define limits $\Delta\theta_{max}$ and ω_{max} and obtain linear working mode and aperiodic response without overshoot. Following procedure is described in [7] and values for maximum angular speed and maximum $\Delta\theta$ are given respectively:

$$\omega_{max} \approx \frac{K_I \Delta\theta}{K_p T_s}, \quad (8)$$

$$\Delta\theta_{max} = \frac{2T_{emax}}{J_m} \left(\frac{K_p T_s}{K_I} \right). \quad (9)$$

In this case very simple position controller can be used. The proportional and integral action is located in the direct path, and it processes the tracking error. The derivative action is placed in the feedback path (Fig. 3). The character of the transient response to small disturbances, where the system operates in linear mode, depends on the zeros of the characteristic polynomial. In a position controlled servo system, the desired step response is aperiodic, arriving the target position without an overshoot. Jerk, torque, speed, and position have smooth transient response under given limits, so the undesirable speed and torque oscillation and wind-up effects are avoided.

5. RESULTS OF COMPUTER SIMULATION

Model of the system (Fig. 2) is verified through the computer simulations using the software package MATLAB/Simulink.

The reference position whose mathematical model is described in section II is generated by S-function. Substation parts of elevator drive and its control is described in sections III and IV. The results are shown in Fig. 4 to 7. Input parameters for the movement of the elevator are:

- Final position of car: 10 [m],
- Nominal speed of car: 2 [m/s],
- Jerk amplitude: 3 [m/s³],
- Elevator capacity: 300 [kg],
- Weight of the car: 200 [kg].

Fig. 4 shows the reference position (θ^*) which leads to the input of the positioning controller and the actual position (θ).

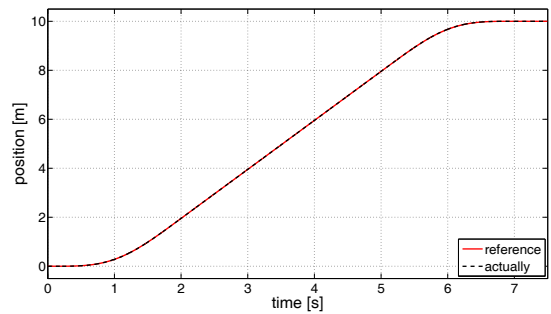


Fig. 4. Actually position and reference position of the car.

It is obvious that the elevator car reaches the desired position without overshoot following the given reference in the whole trajectory.

Difference between the reference and actual position is expressed in millimeters and presented in Fig. 5.

It can be seen that only minor deviations are in the tracking of reference. Also, steady-state error is practically zero.

Fig. 6 shows actually velocity and reference velocity of the car. Reference jerk and actual jerk in the system are shown in Fig. 7. Actual jerk has smooth shape, there

are no sharp peaks and its maximum value is under predefined values.

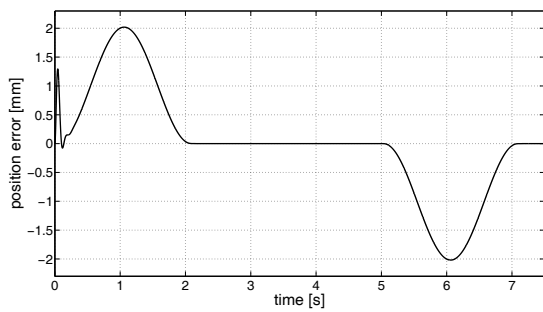


Fig. 5. Difference between reference and actually position (mm).

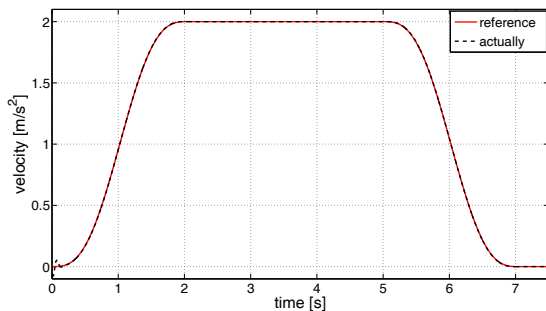


Fig. 6. Actually velocity and reference velocity of the car.

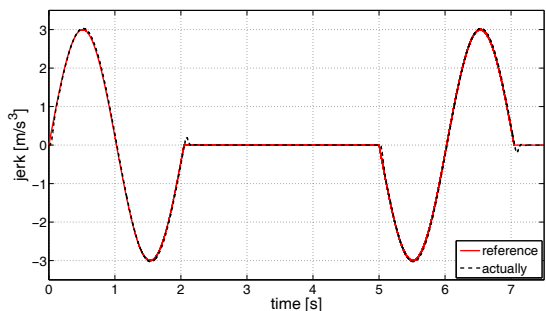


Fig. 7. Actually jerk and reference jerk of the car.

6. CONCLUSION

The paper describes design of simple elevator drive controller which provides tracking trajectory, so the jerk is changed at a predefined function. Parameters of real elevator with permanent magnet synchronous motor drive were included in the model of elevator.

Simulation of the entire system with designed controller is made in the Matlab/Simulink and given results show that design controller meets the requirements completely, smooth and precise position and speed control and defined shape and value of jerk are realized (Fig. 4-Fig. 7).

Position reference is S-shaped function (Fig. 4), so less torque strokes and less tracking error were obtained. Reduced peak values and smooth shape of electromagnetic torque causing lower influence to mechanical subsystem and suppress problems like mechanical resonance sustainable oscillations, etc.

Elevator drive is realized as vector controlled permanent magnet synchronous motor drive but similar control algorithm with position controller can be applied for other types of elevator drive, induction motor drives, etc.

This algorithm should be tested on laboratory prototype which is in the process of implementation.

7. REFERENCES

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