

# Starting Processes in Electric Drive of a Passenger Elevator

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**Abstract:** During the operation of electric induction motors used to drive passenger elevators, electro-mechanical transient processes occur, which can cause unacceptable dynamic loads and vibrations. In this regard, research is needed both at the design stage and for operating elevator systems to determine the arising impact currents and torques, in order to propose solutions for their limitation within pre-set limits. Paper deals with starting processes in a two-speed induction motor drive of a passenger elevator. The equations for the voltages of the induction motor are presented in relative units in a coordinate system rotating at a synchronous speed. The values have been obtained for the torques, the rotational frequencies and the currents when starting at a high speed and passing from high to low speed.

**Keywords:** induction motor, machine model, electric drive, transient analysis, elevator.

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## 1. Introduction

Elevators are stationary lifting systems with periodic action, intended for lifting or lowering people or loads in a cab or platform moving between two or more permanent stops in a specially built shaft on fixed metal rails used to guide the travel of an elevator car in an elevator shaft. These are steel profiles with smooth guide surfaces, the cross section of the profile is usually T-shaped (machine drawn, cold drawn or rolled) [1].

There is no uniform classification of elevators. Different types can be distinguished depending on the type of drive, load, speed, design, etc. The electric elevator is a classic version of a lifting mechanism with tow ropes and a motor. Electric elevators are a tried and tested technical solution for more than 100 years. They are suitable for all types of buildings with heavy traffic. Passenger elevators are the most common type of elevator systems, constantly encountered in our daily lives. The rated speed of electric elevators is usually 1.0 or 1.6 m/s. The drive is carried out by means of a lifting mechanism of gear type with two-speed electric motor or with frequency regulation. In this design, the motor power is transmitted to a friction washer through a gearbox (hence the name - gear drive). Reduction-driven machines use worm gears to control the movement of the elevator by 'rolling' steel tow ropes located above a friction drive pulley that is attached to a gearbox. In addition to electric drive in elevators, it is also found hydraulically, as it is suitable for elevators with a travel of up to 12000 mm and for freight elevators with a capacity of several tons.

For the safety of passengers, a system is usually

provided for moving the elevator down to the nearest stop and opening the automatic doors when the power supply is stopped. Variants of earthquake-resistant elevators with electric drive are also available.

All modern elevators are equipped with the so-called speed limiters that stop the cab when the speed is exceeded at 15%. The probability that the ropes or suspension elements will break and the elevator will 'fall' is reduced to zero. The safety of elevators is regulated by state regulatory documents and controlled by relevant authorities. Elevators are supervised facilities with increased danger of operation and are under the supervision of inspections for state and technical supervision. The maintenance, repair and reconstruction of elevators is carried out by persons (companies) who have received permission to carry out such activity from the state agency for metrology and technical supervision or from authorized officials. The specialist elevator maintenance company must provide 24-hour continuous emergency service.

Elevators are complex technical objects. Today there are many manufacturers of electric motors for them, control units and complete technical solutions - some of them are world-famous elevator companies. It is a fact of elevator traffic that every three years, elevator cabs transport the equivalent of the entire population of planet. As part of the *NowWeMOVE* campaign, April 24 has been declared *Elevator-Free Day* as a global initiative. It can take place anywhere - in offices, shopping malls, public buildings, parking lots, universities and other public or private buildings. The purpose of this event is to draw attention to physical activity for health and to show that in order to move, we do not need to spend time and money.

The main indicators of elevators are: load capacity, speed, productivity and braking accuracy. Other specific definitions related to elevators are: machine room - a



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room where the lifting group (motor and gearbox) and some components of the electrification and control system are located. It is usually located above the elevator shaft; ultimate floor - the top or bottom stop, served by an elevator cab [1].

Motor technologies developed rapidly from the time when in 1889 a directly connected electric elevator appeared, suitable for servicing tall buildings [2]. Later, with the development of technology, multi-speed motors replaced single-speed motors and allowed greater efficiency and conditions for movement. Electromagnetic technologies are replacing manual control and braking. The button control and various complex signaling systems contribute to the further modernization of the elevators. Various security systems are also being introduced, as elevators are the so-called high risk facilities.

Today, sophisticated regulators and switching circuits exist and are used, ensuring precise speed control at all times. Literally all public elevators are automated and have the ability to precisely control and adjust through processor devices with maximum efficiency and security [3]. The development of technology leads to rapid progress in the development of elevator equipment. This contributes not only to increase the comfort and safety of people, but also to reduce the space required for elevator facilities and give aesthetic appearance and durability to the architecture of buildings. The classic shape of the elevators has an electric cable drive with an upper machine room. Recently, electric elevators with machine room with gearless mechanisms with synchronous motors are preferred. [4].

There is a huge interest in the purchase and installation of elevators in recent years. Most orders come from hotels, new housing, shopping malls and business buildings. Prices range widely, depending on three main factors - domestic or imported production, size and load capacity, luxury interior design, degree of automation. According to the standards of the European Union, for example, the elevators must have automatic doors and have access to the relevant symbols for the disabled.

## 2. Technical considerations

The electrical equipment includes motors and devices for selecting the direction of movement, starting and stopping, reducing the speed before stopping, precise stopping, opening and closing the doors, stop during a call, locks and protections, lighting, alarms, etc. Electric motors for elevators are manufactured in special series in order to meet the increased requirements for them, namely: to have a high starting torque; to provide transient processes for the shortest possible time; to be able to adjust the speed, etc. The two-speed induction electric motors with constant torque for both speeds are used in cranes, elevators, metalworking machines, etc. When switching the winding to a larger number of pole pairs (lower synchronous speed), the motor rotates in the direction of the rotating field, due to which the electric machine works as a generator and gives energy to the mains. The low energy consumption meets the latest energy efficiency requirements, and the choice of an optional regenerative drive (braking energy is used)

allows the carbon footprint and elevator operating costs to be further reduced.

In view of the precise braking and the need for low speeds for a more comfortable ride for mass elevators, two-speed induction motors with a squirrel cage rotor are used [5]. The high speed is used for starting and moving with a set speed between the floors, and the low speed - for deceleration and precise stopping. Usually the high speed winding of these motors is dimensioned for cycle duration factor (CDF) 50% and for low: CDF 10%. In some cases, frequency control is used to ensure smoothly dynamic movements - the ideal solution for new and modernization of old elevators [6]. When upgrading, the replacement option with high-efficiency electric motors of a higher energy class should also be considered.

Most electric motors are designed to run at maximum efficiency at full load, but in practice this is rare. Controllers, often called 'voltage regulators', constantly regulate the voltage at the motor terminals so that it corresponds to the instantaneous load. In this way, losses of power and energy are minimized.

Sometimes in practice the question is whether to use a simple induction motor with a frequency regulator or to apply a two-speed electric motor. In many cases, the relatively complex and more expensive frequency inverter can simply be replaced by a two-speed electric motor. This 'trick' applies when the only requirement for the machine is to run at high and low speeds [7]. The electronic component base constantly lowers its price, but with the entry of electronic components to a new higher level with improved technology leads at the same time to the fact that the control device for an electric motor is always more expensive than the price of the object controlled.

Another option is to use an electric motor with forced cooling. This allows to achieve number of switches per hour 240 sw/h for inverter-controlled motors or number of switches per hour 180 sw/h for two-speed motors [8].

The determination of the static and dynamic loads in the elevators has a lot in common with that of the lifting mechanisms in the cranes, but there are features related to the presence of counterweight - a component which provides tension between the towing pulley and the suspension ropes and which consists of a set of weights. The counterweight reduces the amount of force (and hence the required torque and power of the electric drive motor) required to drive the cab, is positioned in the elevator shaft and moves on a separate rail system. The weight of the counterweight is usually equal to the weight of the cab plus 40-50% of the elevator's load capacity. This equalizes the loads during lifting and lowering. The efficiency of elevators has lower values than those of crane lifting mechanisms because it includes additional friction losses in the guide metal rails. When raising an empty cab, in fact, the counterweight will lift the empty cab, and the motor will operate in generator (braking) mode.

The analysis of the mathematical expressions of the static loads in the presence of counterweight shows that the large loads during lifting and lowering of nominal load decrease in comparison with those without counterweight, and the small loads during lifting and

lowering of empty cab increase. Obviously, the value of the weight of the counterweight is important for choosing the power and will depend on the mode of operation of the elevator. If the elevator is constantly being raised and lowered fully loaded, a value must be selected, when lifting at full load and lowering an empty cab - another value and in another operating mode a corresponding value.

The highest values of the total resistance forces and corresponding torques arise in two cases - lifting a nominally loaded cab, standing at the lowest stop and lowering an empty cab from the top stop. The required moment of inertia is determined depending on the minimum time for starting (or stopping) the elevator with passengers in the cab for the two heaviest modes for acceleration during the operation of the elevator - raising one passenger and lowering a full cab.

When choosing an elevator, the drive mechanism must also be taken into account. When determining the power of the electric motors driving elevator systems, it is necessary to know: the kinematic scheme, the load capacity, the weight of the cab and the counterweight, the speeds of movement, the admissible accelerations and decelerations, the number on the floors, the distance between the floors, the operating duty of the elevators and other parameters. The operating duty is determined by the purpose of the elevator and the conditions under which it operates. The lifting elevators, included in current technological lines, have a uniform load schedule with cyclically arriving loads. In the case of passenger elevators, the working conditions largely depend on the purpose of the building in which the elevator operates. In all buildings the peak load is in the morning and in the evening (before and after the end of working hours). In residential buildings and hotels the largest flow of passengers is in the morning directed downwards, and in the evening - upwards, and in administrative buildings it is the opposite - in the morning upwards and in the evening downwards. In case of intensive passenger traffic, it is recommended to build several elevators operating with common control (duplex, triplex). [9].

The power of the electric motors is calculated for peak operating modes, and only in some specific cases a calculation for normal daily operating mode is required.

The calculation of the required power of the electric motor is reduced to pre-selection of the electric motor according to the simplified load diagram, drawing of the exact load diagram taking into account the transient modes and checking the selected electric motor by the methods of equivalent current or torque for cycle of operations that the motor is correctly selected and will not heat up unacceptably at high and low speeds. In addition to this, it is necessary to check for short-term overload at the torque - the multiplicity of the maximum load torque and the permissible multiplicity for overload at the torque of the selected electric motor are compared. When checking the accelerations during starting of the elevator has been done, and with already selected electric motor and brake, the satisfaction of the permissible values can be ensured by changing the flywheel of the system.

Elevator solutions with various applications are currently available in Bulgaria. Some of them are made in

Bulgaria, others are developments of foreign companies, which are also available on our market. The focus of the various product offerings is energy efficiency, safety and optimality of the elevator solution - important factors for choosing products and technologies for implementation in new buildings and for replacement of obsolete facilities with the development of modernization solutions. In essence, modernization can be partial or complete. The partial modernization consists in the replacement of individual components of the elevator in order to improve some of its characteristics.

The choice of control mode for frequency drives strongly depends on the application. The three main control modes are scalar (volt / frequency  $V / \text{Hz}$ ), vector or with field orientation control. For drives using  $V / \text{Hz}$  control, an operating flow is directly involved in the formation of the operating shaft of the motor shaft. There are regenerative inverters on the market that return the regenerative energy back to the power supply network, without the need for braking resistors, with an electric meter for regenerative and motor mode of operation to record the efficiency of the regenerative system. Vector frequency drives have precise torque control over a wide speed range without having to use speed feedback. Frequency drives with field orientation control use a feedback encoder to obtain information on motor speed and possible travel faults. The choice depends entirely on the tasks to be performed and the type of equipment. It often takes a lot of time and effort to install an encoder on older machines, and in some cases this is not even possible. In this case, the best and easiest solution is to operate the machine without feedback.

When controlling hoists, the frequency regulators show clear advantages, but the use of a combination of a frequency converter and a regenerative module can save up to 70% in individual cases compared to elevators with standard two-speed electrical or hydraulic technology. If a large load needs to be slowed down quickly, a dynamic braking resistor or regenerative module must be used to return the regenerative current back to the mains. Also, the smooth start provides comfort in the elevators.

### 3. Factors and decisions influencing final energy consumption

About a third of energy consumption in European countries is accounted for by residential buildings. Due to the increased needs and requirements of users, energy consumption in buildings has recently increased significantly. For this reason, it has become one of the main reasons for the increase in carbon emissions and the continuous efforts of the countries to improve energy efficiency and the use of renewable energy sources [10]. For this reason, it has become one of the main reasons for the increase in carbon emissions. Therefore, the untapped potential for energy savings exists in terms of energy efficient equipment, investment decisions and behavioral solutions in these sectors. This fully applies to elevators [11].

Research shows that around 4.8 million elevator facilities are in operation within the European Union. The number of elevators operating in Bulgaria is over 70,000, and about 60,000 of them are obsolete, over 20 years old.

Understandably, along with the important issue of their safety, the issue of their energy consumption is also relevant. Other studies show that elevators account for about 3 to 5% of final electricity consumption in a building. Their annual consumption is determined by three main factors: the volume of energy consumed at rest; the necessary energy in the process of work; frequency of use of the facility. Energy consumption while a facility is in operation and during the idle period is determined mainly by the technical characteristics of the system components and their energy efficiency. This means that these factors are determined at the level of design and actual construction of elevators, as well as in the stages of its installation, which, once set, as a rule should not undergo significant changes during the operation of the system. Alterations can occur in the process of aging and wear (which contribute to increased friction, for example). The consumption values in the two operating modes of the facility are largely independent of each other. Low energy consumption during the transport of passengers and cargo does not always mean low consumption at idle, and vice versa.

What determines the frequency of travel, along with the location, is the purpose for which the elevator is used (providing an accessible environment, opportunities to transport goods, etc.), as well as the nature of the groups using the facility. Elevators in residential buildings are in most cases not as frequently operated as those in public buildings such as hospitals. It is these differences in frequency of use that can mean a wide range of energy consumption on an annual basis, even in the case of facilities of similar design.

According to estimates based on international research, the results of measurements of consumption at idle present data in a very wide range. Experiments show that in the residential and commercial sectors, there are very different values of consumption. This dispersion can be explained by the different energy efficiency of the components used and by the choice of specific equipment. With regard to energy consumption in the process of moving passengers and goods, monitoring of absolute values shows that there is no basis for any definitive comparison of the different elevators. Here the comparisons would be based on the technologies used by the manufacturer.

Although all elevators consist of similar elements, there are varieties into which they are divided, depending on different structural elements. The most common division is according to their drive. The direct comparison between the two main types of elevators by this criterion - hydraulic and electric, certainly gives an advantage to the second technology. Hydraulic elevators, however, are suitable for servicing buildings with no more than 6 or 7 floors. In this case, they are the most profitable solution. As the height of the building increases, electric elevators are indicated as more suitable.

#### **4. Potential for energy saving and their implementation**

Based on numerous research, scientists conclude that if efforts are made to exploit the potential of elevators through the consistent use of the best available

technologies (including high-performance devices and components, such that allow the inclusion of standby mode when the facility is not in operation) about 60% of the energy consumed for the operation of elevator facilities in European countries could currently be saved [11].

An important issue concerning the use of energy efficient solutions in elevator technologies is the fact that their choice is in most cases part of the obligations of construction companies, which after completion of construction, rent or sell the building, along with the implemented solutions. Here comes the question of the lack of motivation of the builder to implement highly efficient technology, costing more, instead of focusing on a more cost-effective financial solution, which in the future will generate higher costs for its users.

Two of the trends in the development of energy efficiency of elevators encourages innovation in the development of drive systems. Increasingly, consumers are demanding systems that take up less space and therefore stop choosing equipment without a machine room. In this case, the advantages are in terms of drive modes. There is also a positive trend in the development of the systems themselves towards innovative solutions and new design. Such compact solutions are already available on the market, as well as the replacement of steel ropes with other options that are more durable and also reduce the need for additional lubrication.

Some manufacturers offer state-of-the-art software control systems. The basic elements of such a system are considered to be the possibilities for fixing certain rules, such as the exclusion of certain elevator facilities at night and on weekends. In order to reduce costs, it is possible to add additional features as well as increase operational flexibility. For example, in some systems, the cabs are set to be positioned at a certain point in time, such as all elevators returning to the ground floor in the early morning hours to accommodate the increased volume of passengers. This reduces the waiting time. Some manufacturers offer passenger flow control solutions that allow the optimization of the used equipment by floors and the reduction of the energy used.

#### **5. Characteristics of electric drives for elevators**

Elevator controls are available in the power range from 2.2 to 32 kW and are a reliable choice for many of the newly built elevator systems and in the modernization of older elevators. Some of their more important features are the following, and the purpose of all functions is to meet the needs of the market [12]:

- Four quadrant intelligent elevator control system (adjustable parameters of the elevator - times for acceleration / reduction of speed, set of speeds, etc.) and rapid response to process changes due to dynamic vector control; regenerative solutions as option, and hence reduced energy costs, as the regenerative power supply returns excess braking energy back to the grid; highly efficient vector control algorithm - controls the orientation of the field (FOC); optionally sensorless motor control for operation without feedback;

- Flexible digital torque control - preset torque (torque limit - parameters setting allow separate limits in four quadrants); smooth release and application of the brake, without the need for additional measurement of the weight of the load;
- Inertia monitoring (inertia compensation) – speed optimization; overshoot and anti-vibration control;
- Integrated safety functions - initial phase check, motor protection (temperature monitoring via electronic thermal overload relay), overvoltage/under voltage protection;
- Drive control in the event of an trouble; smoothly reduction of speed in case of power loss; increased tolerance in the permissible variation of the supply voltage:  $\pm 15\%$ ;
- Full range of protection functions: precise current measurement, multi-level overload protection, current overload, short circuit; built-in EMI-filter; Built-in data black box function, record the elevator running state data before fault to help analysis fault cause;
- Control algorithms: the purpose of these algorithms is to optimize the movement of the cab and provide reduced depreciation of mechanical parts, reduce electricity consumption and reduce passenger service time.

In connection with the use of electronic devices for elevator control it is necessary to pay attention to the so-called indicators for the quality of electricity. In other words, whether these devices do not influence in any way the parameters of the electrical network from which they are powered. In this regard study of the impact of various parameters of the physical environment on the design and

operational indices of energy efficiency has been carried out in [13]. The results obtained make it possible to identify specific measures to improve the indices and bring them into regulatory norms.

## 6. Determination of the mechanical characteristics of the electric motor

The electromechanical transient processes in a two-speed passenger elevator powered by an AC200M-24/6 electric motor are studied. The static mechanical characteristics obtained are presented in Fig. 1. The mechanical characteristics of the motor are calculated for high and low speed, using the expression:

$$M = \frac{M_m (2 + 2s_m)}{\frac{s}{s_m} + \frac{s_m}{s} + 2s_m}, \quad (1)$$

where  $M_m$ ,  $s_m$  are maximum torque and slip values, and  $M$ ,  $s$  – going values.

## 7. Model of two-speed induction motor electric drive

The study of electromechanical transient processes in an induction motor is performed under generally accepted assumptions [14]. The voltage equations for the windings of an induction motor are presented in relative units in a coordinate system that rotates at the synchronous angular speed of the stator fields. Expressing the full magnetic flows by means of the corresponding currents and presenting the obtained expressions in view of the convenience of solving them in the form of *Cauchy* we get

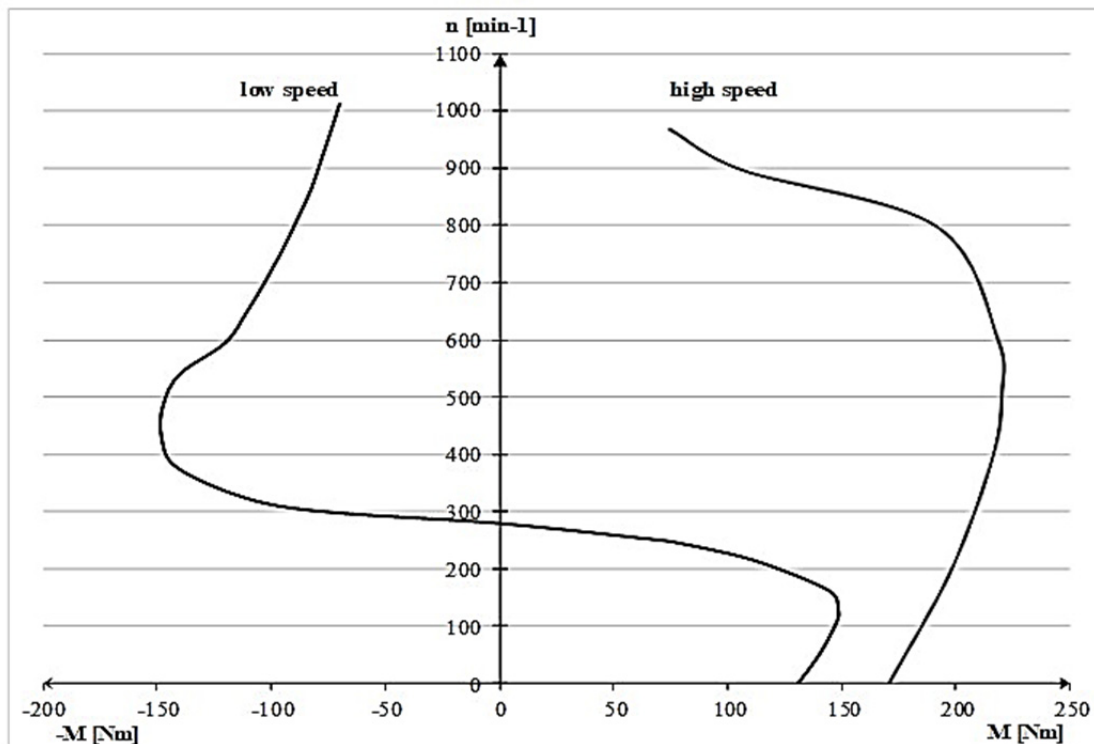


Fig. 1. Static mechanical characteristics for high and low speed.

$$\begin{aligned}
\frac{di_{sx}^*}{d\tau} &= \frac{1}{L_{eq}^*} \left[ u_{sx}^* L_r^* - u_{rx}^* L_m^* - r_1^* L_r^* i_{sx}^* + r_2^* L_m^* i_{rx}^* + i_{sy}^* \left( L_s^* L_r^* - s L_m^{*2} \right) + L_r^* L_m^* (1-s) i_{ry}^* \right]; \\
\frac{di_{sy}^*}{d\tau} &= \frac{1}{L_{eq}^*} \left[ u_{sy}^* L_r^* - u_{ry}^* L_m^* - r_1^* L_r^* i_{sy}^* + r_2^* L_m^* i_{ry}^* + i_{sx}^* \left( s L_m^{*2} - L_s^* L_r^* \right) + L_r^* L_m^* (1-s) i_{rx}^* \right]; \\
\frac{di_{rx}^*}{d\tau} &= \frac{1}{L_{eq}^*} \left[ -u_{sx}^* L_m^* + u_{rx}^* L_s^* + r_1^* L_m^* i_{sx}^* - r_2^* L_s^* i_{rx}^* + i_{sy}^* \left( s L_s^* L_r^* - L_m^{*2} \right) + L_s^* L_m^* (1-s) i_{sy}^* \right]; \\
\frac{di_{ry}^*}{d\tau} &= \frac{1}{L_{eq}^*} \left[ -u_{sy}^* L_m^* + u_{ry}^* L_s^* + r_1^* L_m^* i_{sy}^* - r_2^* L_s^* i_{ry}^* - i_{rx}^* \left( s L_s^* L_r^* - L_m^{*2} \right) + L_s^* L_m^* (1-s) i_{sx}^* \right]
\end{aligned} \tag{2}$$

where  $i_{sx}^*, i_{sy}^*, i_{rx}^*, i_{ry}^*$  - model stator and rotor currents (p.u.) respectively;

$u_{sx}^*, u_{sy}^*$  - model stator voltages; since the motor is a induction type with squirrel-cage rotor the model rotor voltages  $u_{rx}^* = 0$  and  $u_{ry}^* = 0$  ;

$L_s^*, L_r^*, L_m^*, L_{eq}^*$  - stator, rotor, mutual and equivalent inductance (p.u.) respectively;

$\tau = \omega_b t$  - time in relative units.

The electromagnetic moment is obtained:

$$M^* = \frac{M}{M_N} = \frac{3}{2} \cdot \frac{p u_b i_b}{\omega_b M_N} (i_{sy}^* i_{rx}^* - i_{sx}^* i_{ry}^*), \tag{3}$$

where  $u_b, i_b, \omega_b, M_b$  - basic values of voltage, current and angular speed, respectively.

$p$  - pole pair number;

$M_N$  - rated torque.

The mechanical equipment of the two-speed elevator is presented with a single-mass dynamic model. The equation of motion will be:

$$M^* - M_L^* = \frac{J_\Sigma \cdot \omega_b^2 ds}{p \cdot M_N d\tau}, \tag{4}$$

where  $M_L^*$  - torque of the load (p.u.);

$J_\Sigma$  - total moment of inertia of the electric drive (that of the electric motor and that of the mechanical part of the elevator).

After conversion is obtained:

$$\frac{ds}{d\tau} = - \frac{p \cdot M_N (M^* - M_L^*)}{J_\Sigma \cdot \omega_b^2} = - \frac{p}{J_\Sigma \cdot \omega_b^2} (M - M_L), \tag{5}$$

where  $u_A^*, u_B^*$  and  $u_C^*$  are phase voltages (p.u.).

The following dependences are used to calculate the phase stator currents:

$$\begin{aligned}
i_A^* &= i_{sx}^* \cos \tau - i_{sy}^* \sin \tau; \\
i_B^* &= i_{sx}^* \cos \left( \tau - \frac{2\pi}{3} \right) - i_{sy}^* \sin \left( \tau - \frac{2\pi}{3} \right); \\
i_C^* &= i_{sx}^* \cos \left( \tau + \frac{2\pi}{3} \right) - i_{sy}^* \sin \left( \tau + \frac{2\pi}{3} \right).
\end{aligned} \tag{6}$$

## 8. Results obtained

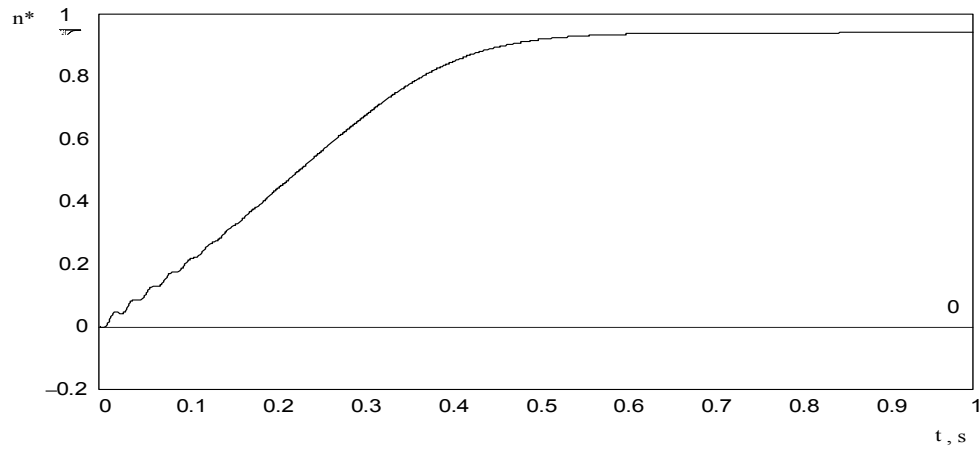
In the studied electromechanical transients, the electric induction motor operates in motor and generator mode, as the slip varies widely. Therefore, the slip-dependent parameters of the equivalent circuits of its windings will also change. If you work with variable parameters, the analysis would be complicated many times. From the comparisons of the results for transient processes obtained by calculation and experimentally in [14] it is found that the best match is achieved when the parameters of the machine are chosen for slip, corresponding to the initial speed of the transient process. Therefore, for modeling the starting processes, it is appropriate to use parameters corresponding to the slip value  $s=1$ . The studies use the parameters of the equivalent circuits of the electric motor, which are determined by a calculation method for slip  $s=1$ . In the studies, when the operation of the electric motor changes from one speed to another, the model changes, replacing the parameters of the electric motor and the initial slip for the respective rotational frequency. When studying the transient processes when lowering a full cab, the sign before the load torque ML changes.

It is known from practice that the reduced total moment of inertia  $J_\Sigma$  of the elevator is several times

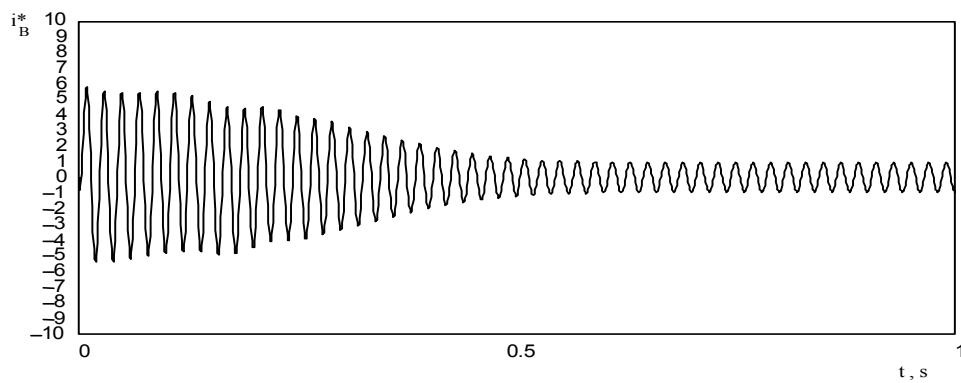
greater than the moment of inertia  $J$  of the electric motor – in research we accept  $J_\Sigma = FI \cdot J$  as the coefficient of inertia  $FI$  is chosen equal to 2.5.

To solve the differential equations system consisting of (2), (3), (5) and (6) the software MathCad® of Parametric Technology Corporation (PTC®) has been used and specifically laid down therein functional method Rkadapt - method for solving differential equations with adaptive size of approximating step [15]. As a result of the research, the dependences of the rotational speed  $n^*$ ,

the torque  $M^*$  and currents  $i_A^*, i_B^*, i_C^*$  have been obtained for high-speed start-up and switching from high-speed to low-speed when raising and lowering a full cab. Some of the obtained results are given below - Figures: 2 ÷ 13.

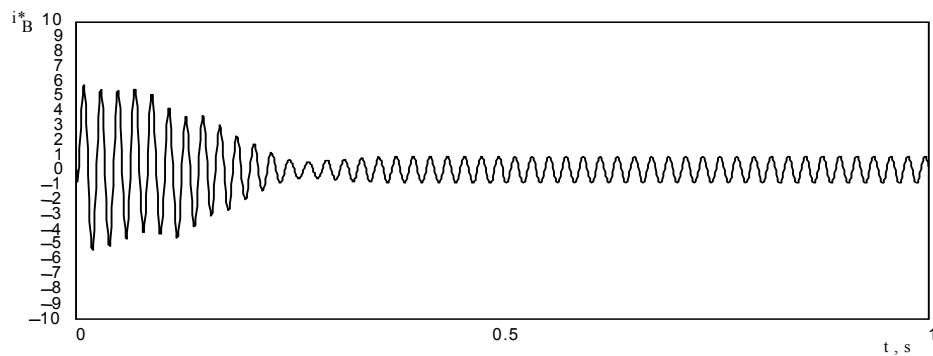


**Fig. 2.** Variations of the rotational frequency in case of starting at high speed when raising a full cab.



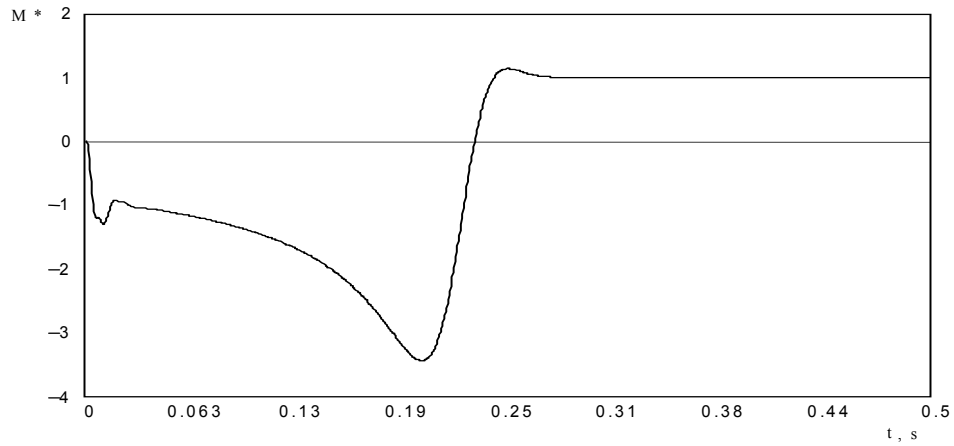
**Fig. 3.** Variations of the phase stator current in case of starting at high speed when raising a full cab.

**Fig. 4.** Variations of the rotational frequency in case of starting at high speed when lowering a full cab.

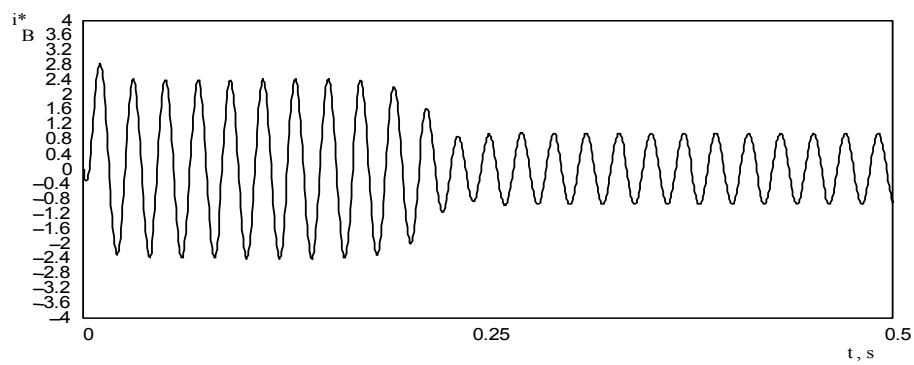


**Fig. 5.** Variations of the phase stator current in case of starting at high speed when lowering a full cab.

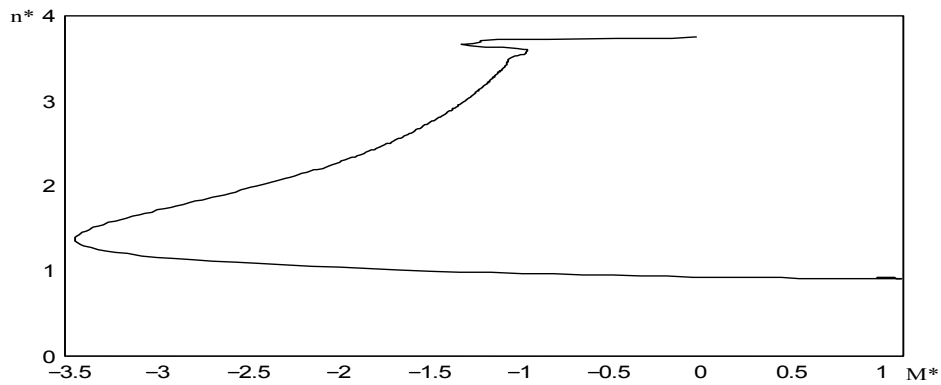
**Fig. 6.** Variations of the rotational frequency in case of transition from high to low speed when raising a full cab.



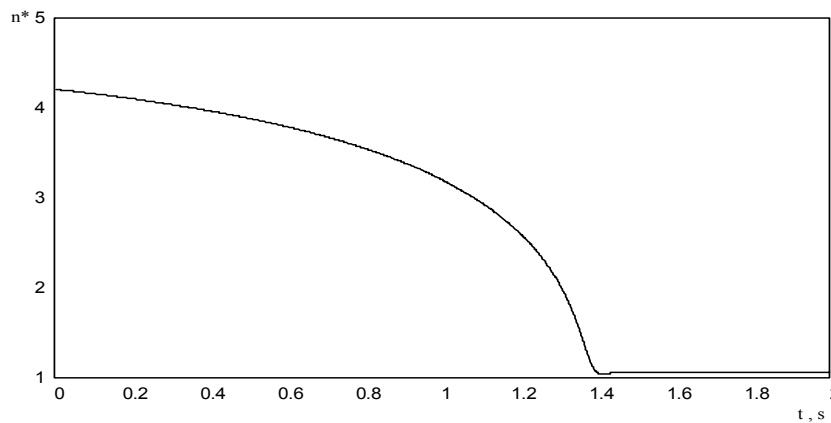
**Fig. 7.** Variations of the motor torque in case of transition from high to low speed when raising a full cab.



**Fig. 8.** Variations of the phase stator current in case of transition from high to low speed when raising a full cab.



**Fig. 9.** Mechanical characteristic in case of transition from high to low speed when raising a full cab.



**Fig. 10.** Variations of the rotational frequency in case of transition from high to low speed when lowering a full cab.

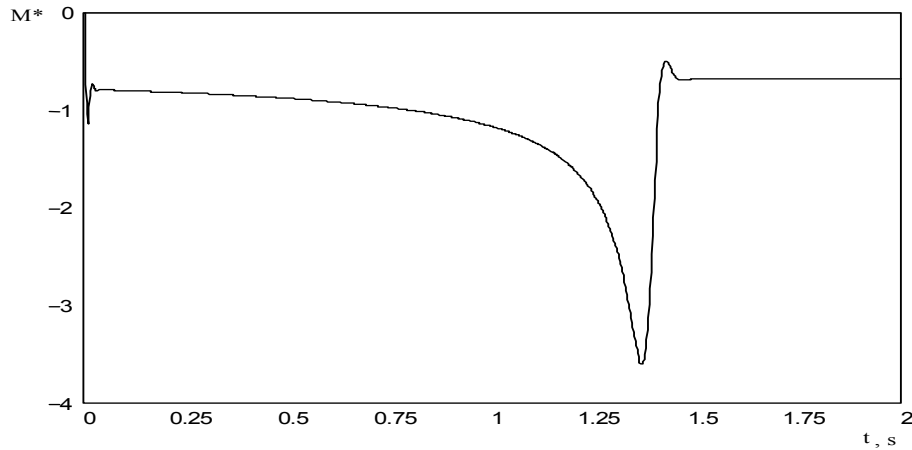


Fig. 11. Variations of the motor torque in case of transition from high to low speed when lowering a full cab.

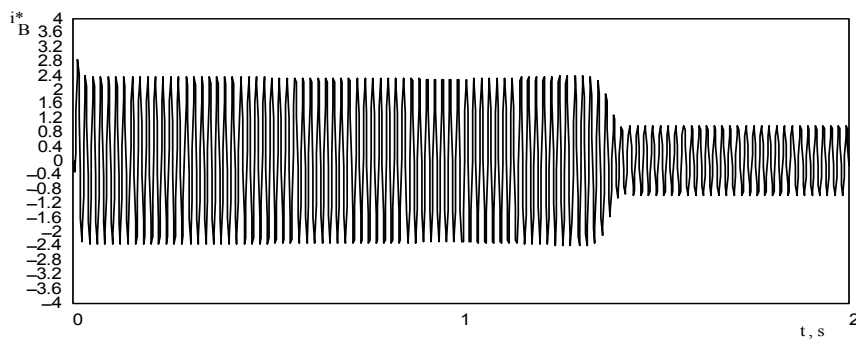


Fig. 12. Variations of the phase stator current in case of transition from high to low speed when lowering a full cab.

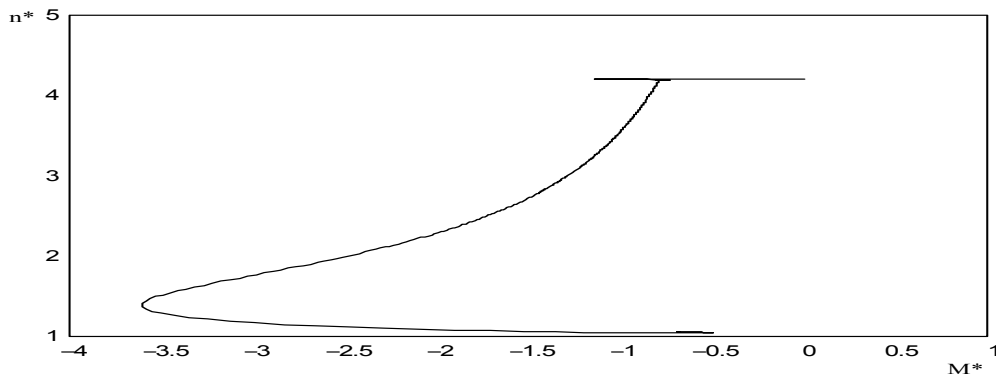


Fig. 13. Mechanical characteristic in case of transition from high to low speed when lowering a full cab.

An important indicator that has a decisive influence on the transient dynamic processes of electric drive is the electromechanical time constant:

$$T_M = \frac{J \Sigma \omega_1}{M_N} s_N \quad (7)$$

In engineering practice, this is considered to be the time required for the electric motor to rotate at angular speed  $0.633\omega_1$ . Often its predefining is used to coordinate settings and protections.

For the considered motor type AC200M-24/6 the electromagnetic time constant is determined on the basis of its technical parameters and for the most loaded case of operation of the elevator:

$$T_M = \frac{0.29275 \times 1000}{73.84} \cdot 0.03 = 0.119 \text{ seconds.}$$

## 9. Conclusion

With the help of the developed model the ongoing transient processes in the electric motors and the kinematic mechanical schemes of elevators can be studied. A solution could be sought to the opposite task - the development of an electric drive with parameters that ensure the flow of transient processes under pre-set requirements by the user. The reliability and operability of the proposed model has been tested experimentally in previous studies of the authors for induction motors with different rated power and the match between the computational and experimental results is very good, within 5% discrepancy.

## Appendix

Technical data for electric motor AC200M-24/6:

Low speed:  $P_{N_1}=1.9$  kW;  $U_{N_1}=400$  V;  $I_{N_1}=24.00$  A;  $n_{N_1}=240 \text{ min}^{-1}$ ;  $I_{START_1}=30.00$  A;  $r_1=1.812 \Omega$ .

High speed:  $P_{N_2}=7.5$  kW;  $U_{N_2}=400$  V;  $I_{N_2}=17.00$  A;  $n_{N_2}=970 \text{ min}^{-1}$ ;  $I_{START_1}=67.00$  A;  $r_1=0.617 \Omega$ .

$$J=0.1171 \text{ kgm}^2.$$

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