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Computer modeling of electromechanical system of two-speed elevator

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ABSTRACT

Today, elevator production in Ukraine needs innovative solutions and changes, because most of the equipment in operation was built and installed in the 70-80s of the last century. Due to the high cost of new frequency-controlled winches and the complexity of maintenance, the search for modernization and improvement of existing elevator winches remains an alternative. No less important stage of operation is diagnostics. Timely detection of damages and forecasting of future failures allow to provide high-quality work during all term of operation, and also to reduce expenses of budgetary funds for difficult repairs. Computer simulation plays an important role in the modern world both during the design of a new elevator and during operation. Thanks to fairly simple and clear programs, it is possible to reproduce not only the standard modes of operation of the mechanisms, but also to perform calculations of future possible faults. The use of visualization facilitates the perception of information for operators, engineers and other users involved. The paper presents a computer model of a two-speed elevator with an induction motor and a reduction winch. The research used Matlab / Simulink software, which is intuitive to use and, in the full sense of the word, informative. The built model of the elevator has feedback on the calculated load of the cabin. The latter is determined by the transients during engine start-up and affects the positioning accuracy at a stop. The dependences of the influence of the degree of cab loading on the positioning accuracy are found. In the second stage, the supply voltage parameter is added. A change in this parameter within ± 10% affected the previous calculations of the loading degree and deteriorated the accuracy by almost three times. At the same time, most indicators (75%) meet the requirements of international standards EN 81-20: 2014 with positioning accuracy in the range of ± 10 mm. In further studies it is planned to use the obtained results to reduce the sensitivity of the algorithm for calculating the loading degree of the cabin to change the supply voltage and ensure the required positioning accuracy in the entire load range of the cabin when changing the supply voltage ± 10 %.

Keywords: Computer simulation; diagnostics; automated control systems; two-speed elevator; identification method; positioning accuracy

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INTRODUCTION

In today's world of technology, it is difficult to catch up with new ways to diagnose, adjust and improve automatic control systems implemented at the largest manufacturers of elevators. However, the modernization and maintenance of already commissioned elevators forces service personnel to use different diagnostic methods and requires specialists to have a wide range of knowledge in this field due to the large variability of control systems.

The constant increase in requirements for safety and quality of execution of elements of elevator equipment necessitates changes in the commissioned elevator installations. The modern world has almost completely switched to control systems using frequency control of the speed of the motor shaft, which provides smooth movement, high comfort and relatively low power consumption. However, such installations require high material costs for both manufacture and installation, as well as maintenance during operation. That is why control system for two-speed asynchronous motors without frequency control is highly competitive due to the ease of manufacture and maintenance, compared to frequency-controlled winches.

To date, in elevator construction, most electric drives are made of two-speed asynchronous type with a short-circuited rotor. The relay-contactor circuit is most often used as a control system. However, the main disadvantage of such schemes is the low reliability, which in turn leads to periodic deviations of the settings. The latter affects the characteristics of the motor, increasing current and voltage fluctuations in both the control system and the power supply system.

Based on the above, given the mass of exploited facilities of this type in the post-Soviet space, and not only, it is important to find alternative ways to diagnose a particular type of automatic control systems. The results of computer simulation of electromechanical systems (EMS) and their diagnosis will further determine the most effective way to upgrade obsolete equipment to save material costs, while meeting the modern parameters of safety and reliability of elevators.

The main purpose of the diagnosis of elevator equipment is the timely detection and prevention of possible malfunctions. The essence of the diagnostics includes certain changes in the parameters of the elevator equipment at the time of commissioning with the current state. This safety analysis allows the use of special places that require replacement or adjustment, to maintain the efficiency of the elevator to comply with the rules and the reliability of their operation.

There are many types of diagnostic procedures, consider the main ones. The first, of course, is a visual inspection: the presence of defects in the elements; wear of moving parts; lack of lubricants, where they are needed; darkening of contact groups on the relay circuit, etc. All this requires immediate replacement with new ones in order to avoid an accident during operation. The second type is functional diagnostics, in which the object is checked at standard loads and daily intensity of operation. The third type of diagnostics will be considered a technical inspection, which involves a number of actions that are not standard in everyday use, but allows you to determine a large number of parameters of the technical condition of the equipment. Most types of diagnostics involve the use of various tools, as well as electronic systems for reading and processing information. Due to modern technologies, there is a variability in the implementation of control systems and information collection in the automatic control system of elevator equipment as a whole, and in its individual sections and elements [1].

In large cities, passenger traffic is quite high, which necessitates research to study and analyze the effective operation of the control system during rush hours in residential buildings and working hours in office buildings. The software of modern elevator control systems facilitates this task and allows you to monitor the dynamics of operation and load in real time [2, 3].

The ability of machines or systems to learn new operations using neural network-based algorithms allows us to have increasingly flexible machines capable of reproducing human learning processes. The machine based on a set of data obtained in real time from the equipment in operation, allows you to calculate all the necessary moments to reduce energy consumption of the installation, as well as increase the efficiency of the mechanisms [4, 5].

All further results of experiments on both the simulation model and the physical equipment depend on the accuracy of the description of the mathematical dependences of the various parameters of the system. The idea of using systems identification theory, which allows you to build a mathematical model of a real dynamical system using available experimental data, is similar to the topic of this study. According to [6], special attention should be paid to uncertainties in the modeling process. It is proposed to model complex systems using a multi-mass approach. This in turn will complicate mathematical calculations, but will lead to more accurate results that are theoretically close to real values. Also the approach to the organization of control of efficiency of operating modes of technological object based on simultaneous control of efficiency of energy consumption and technological parameters for revealing of the reasons of inefficient work is offered. To control the efficiency of energy consumption, it is proposed to use the procedure of comparing the actual energy consumption with its planned value [7, 8].

The improvement of operational properties and reliability indicators is considered as a result of optimization of the pre-series technological system in the framework of product life cycle support. Analysis of wear of system elements is directly related to the safe operation of elevators. Computer models that calculate wear processes due to known coefficients of friction and other parameters, allow to predict the required service intervals of mechanisms, as well as the frequency of their replacement with new ones [9]. Another option is to analyze the operational reliability of vehicles with an emphasis on destructive factors that affect failures. This method includes measures aimed at improving the performance of the mechanized vehicle, diagnostics (assessment of damage based on the diagnostic indicator) and repair work, based on which the concept of risk measures is implemented. As a result of this reliability analysis, one of the conditions is met: suitability or unfitness for operation [10].

There are a number of programs and methods to optimize calculations that simplify the search for the necessary system parameters. The most important thing when using different methods is the similarity of the indications, which indicates the reliability of the selected coefficients and experimental results. Since the complete model of the elevator can be considered as multi-mass, it complicates the calculations due to the large number of parameters that affect the final result. For example, the impact on the accuracy of stopping the degree of sliding in the guides, the accuracy of the brake (without slipping and slipping), stretching the rope depending on the occupancy of the cabin and more. For these calculations can be used shells of complex shapes, made by the method of curved grids in order to optimize the calculation of strength and stability [11].

Analytical research of scientific works of the author's collectives which are engaged in questions of designing of the electric equipment for drives of elevator winches, has shown:

– there are inconsistencies in the technical requirements for electric motors;

– there are significant simplifications of the principles of design and methods of calculating electric motors of winches;

– insufficient volume and further analysis of data obtained during experimental studies of energy performance of electric motors and elevator winches;

– there is no concept of designing shells of elevator electric motors, which is focused on the maximum use of serial parts and components [12].

The training of future professional engineers plays an equally important role in modern education. Highly qualified personnel who are able to find and troubleshoot complex equipment are always highly valued. Simulators play an important role in the learning process, even virtual models of equipment help to understand the basic principle of operation, to study the components of the system [13, 14]. The simulation model of the elevator presented in the environment of the Matlab / Simulink program also allows to master the basic laws of electromechanics. When connecting the visualization of the elevator, you can work out different algorithms of behavior, such as during peak hours and during hours of average passenger traffic. Modeling more complex systems and tracking large-scale energy consumption (such as a district or city) is also an interesting field for research, and modern programs allow you to calculate a huge number of situations in a relatively short period of time [15]. Thus, when installing multiple sensors and bringing them into a single base, you can determine which elevators and in which buildings need repair, modernization or other measures to improve safety and reduce energy consumption [16, 17], [18]. Energy efficiency of systems used in various industries is an important issue in terms of improving the workflow and reducing financial costs [19, 20].

THE AIM OF THE WORK

Investigation by computer modeling of the influence of the voltage change of the two-speed elevator EMC on the positioning accuracy to determine the limits of application of the proposed algorithm for identifying the loading degree of the elevator car.

METHODS, RESULTS AND DISCUSS

A mathematical model of the elevator in the Matlab / Simulink environment was developed for the research.

In fact, the elevator is a rather complex multi-mass elastic dynamic system, in the elements of which in the process of operation there are and are maintained fluctuations of different frequencies.

The main inertial masses are: rotating drive masses; gradually moving car masses with cargo (or passengers), counterweights and balancing ropes or chains. In the process of operation of the elevator oscillations also have the masses of the entire winch with a frame. The main elastic elements of the elevator, which have the lowest rigidity, are the ropes of the cab suspension and counterweights, additional shock absorbers on the suspension of the counterweight, as well as shock absorbers of the winch frame supports on the mine structure.

Thus, in general, the analysis of elevator oscillations requires consideration as a multi-mass elastic dynamic system with a large number of degrees of freedom under the influence of driving or braking forces from the drive, gravity from the cab, counterweight and other balancing elements. as well as resistance forces in the cab guides and counterweights. Considering also that the mass of the winch, which is installed on the shock absorbers, can perform in general not only vertical but also angular movements, the general description of such a dynamic system will require a large number of differential equations of second order, including nonlinear due to for example, variable values of rigidity of ropes of a suspension bracket of a cabin and the counterweight changing the length in the course of work and other factors. Analysis of the solution of the problems of the dynamics of such systems in the form of even with the involvement of sufficiently powerful computers is usually a significant difficulty. Therefore, in the study, the considered system is single-mass [21].

In the initial stage of the elevator car movement, the loading degree of the car is determined by the transient processes of the engine. Next, the time of the start of braking is calculated to ensure the accuracy of the stop. Varying the value of the braking time, it was analytically proved that using the identification method can increase the accuracy of positioning by almost three times. The proposed replacement increases the comfort and accuracy of stopping, and also has a positive effect on the energy efficiency of the system, due to minor over-regulation [22].

According to research, it was found that the characteristics of the winch have the greatest impact on these properties of the elevator, therefore, an important conclusion is made: improving the basic characteristics of the elevator lies in improving the elevator winch system and, above all, the drive motor.

Fig. 1 shows the block diagram of the elevator installation, as well as the impact and dependence of some system parameters on others.

The following notations are accepted in the scheme: m_{gr} is the weight of cargo (passengers); m_{cab} is the cab weight; m_{pr} is the mass counterweight; m_{kan} is the weight of ropes; i is the gear ratio; M_d is the torque on the motor shaft; M_{spb} is the moments of resistance on the drum shaft; M_{sp} is the moments of resistance of brakes; ω_b is the angular velocity of the drum shaft; ω_d is the angular velocity of the motor shaft; ω_r is the angular velocity at the output of the reducer; *AO* is the output signal sensors; *DO* is the winch control system output signal, the block *DRUM* fits the rope driving pulley.

The control part of the elevator equipment, which is an information component of the control system, is responsible for the quality of movement and accuracy of positioning. It calculates the loading degree of the cab according to the method of identification, control of the time of onset of braking and the moment of application of the brake. Thanks to sensors installed on various elements of elevator equipment, it is easier to monitor both the parameters of electrical components (e.g. mains voltage, motor current) and mechanical (stop accuracy on a particular floor, engine shaft speed).

Modeling of automated control systems is an important part of their research and modernization. Many companies at the design stage use various programs to model certain physical processes. At these stages of system design and modeling, it is necessary to keep in mind the variability of parameters and their physical properties [23] and [24].

The advantages of computer modeling include, firstly, the ability to calculate all possible emergencies and non-standard situations without harm to human life and health, which gave a big leap in the development of science and technology, thanks to the safe conduct of experiments both simple and complex physical processes in various fields of activity. Secondly, the simulation and visualization of the system makes it possible to track changes in the characteristics with high accuracy for a minimum period of time [25, 26]. Computer graphics allow you to see the system in real time, taking into account the physical properties of the equipment. This feature allows developers to take into account certain modeling errors so as not to repeat them when testing real equipment. Studies in the field of electrical and energy performance of both engines and the entire control system do not go unnoticed [27]. For example, a voltage regulator for energy-efficient asynchronous drive control is an alternative to price-quality control. This method is effective for a number of fixed loads in static mode in the absence of automatic voltage regulation [28]. However, frequency drives are becoming increasingly popular due to the high positioning accuracy compared to other control methods. Continuous research in this direction allows us to find the optimal control parameters to select the most suitable for a particular situation of acceleration and deceleration times [29].

The simulation model of the elevator (Fig. 2) is a complex system of dependencies [5]. Due to the large number of factors that affect the operation of the system, the model simplifies the consideration of the elevator mechanism as a single-mass system. The description of the engine operation is presented through the Kloss formula. The elevator unit with a maximum load of 1500 kg and a 4AN-250-6 / 24NLB engine with a capacity of 16/4 kW was used as a basis. The calculation is based on six characteristics of engine acceleration at loads from 0 to 100 % in increments of twenty percent. An example of transients under these loads is presented in Fig. 3.

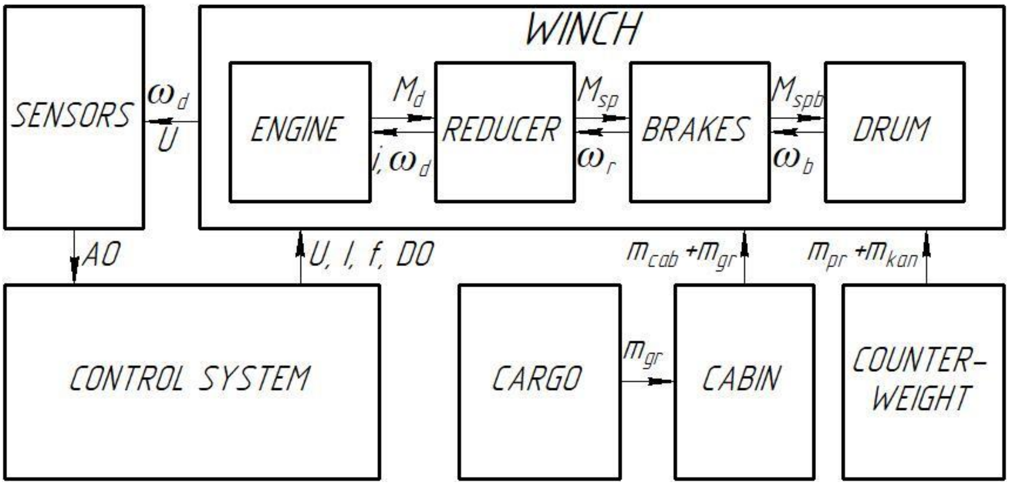

Fig. 1. **Block diagram of the elevator installation**
Source: **compiled by the authors**

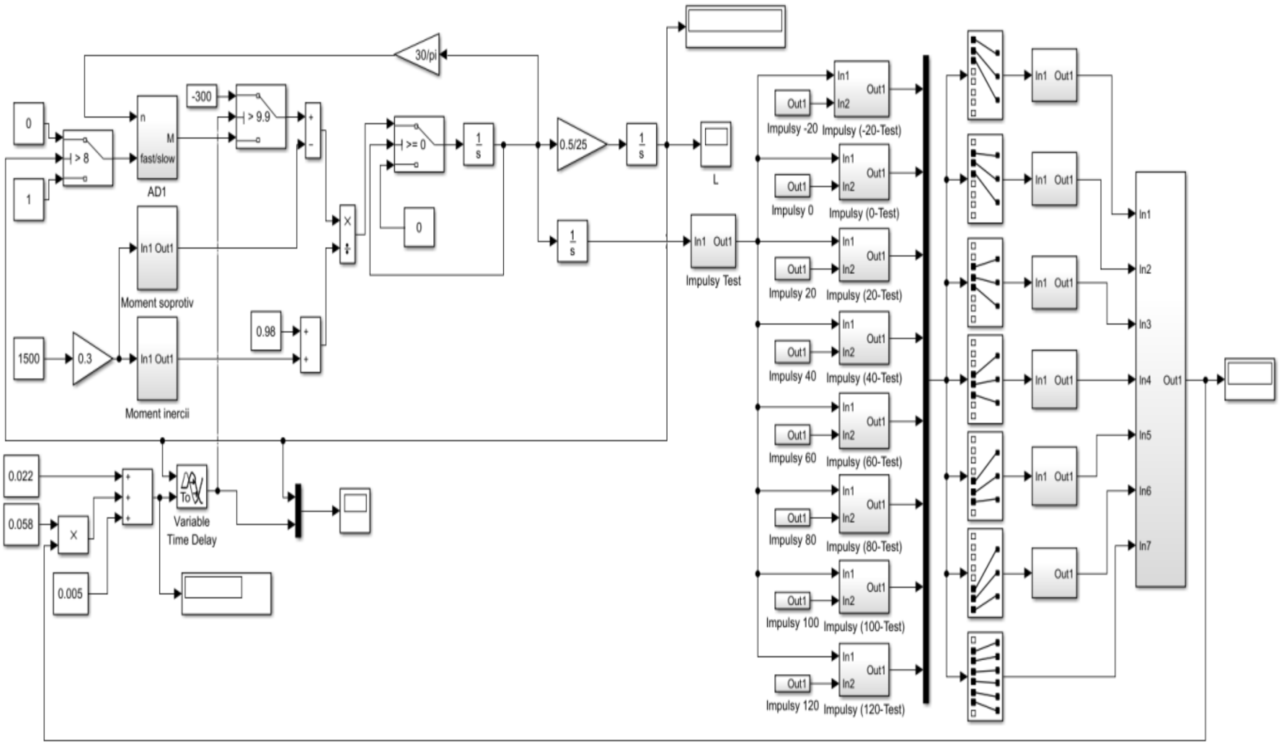

Fig. 2. **Simulation model of an elevator installation with a control system in the Matlab / Simulink environment**
Source: **compiled by the authors**

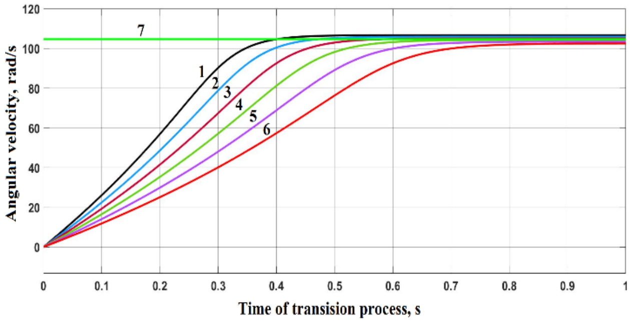

Fig. 3. **Transients during engine start**
Source: **compiled by the authors**

Formula (1), which describes the operation of the elevator, has a parameter of the supply voltage that changes during operation of the installation in different directions of deviation from the nominal value. This deviation gives an error in calculating the degree of loading of the cabin, because it is located directly in the inner circuit of the engine and affects the transient process.

$$\left[\frac{r^2\cdot(m_{gr}+m_{cab}+m_{pr}+m_{kan})}{i^2}+J_0\right]\cdot\frac{d\omega}{dt}=$$
$$=\frac{2\cdot M'_{cr}\cdot\left(\frac{U_1}{U_{1n}}\right)^2\cdot(1+a\cdot s_k)}{s/s_k+s_k/s+2\cdot a\cdot s_k}-\frac{g\cdot r\cdot(m_{gr}+m_{cab}+m_{pr}+m_{kan})}{2\cdot i\cdot\eta_n},\quad(1)$$

where r is the radius of the rope pulley; m_{gr} is the weight of cargo; m_{cab} is the cab weight; m_{pr} is the mass counterweight; m_{kan} is the weight of ropes; i is the gear ratio; J_0 is the the moment of inertia of the rotor; η_n is the efficiency of lifting installation taking into account friction in guides; *Mcr* is the critical moment when turning on the stator with rated voltage; *U1* is the voltage value different from the nominal one; *U1n* = 380V is the rated voltage.

Computer simulation allows you to track changes in settings at each stage of a particular process. For example, in Fig. 4 shows a model that reproduces the pulse graph of the encoder installed on the motor.

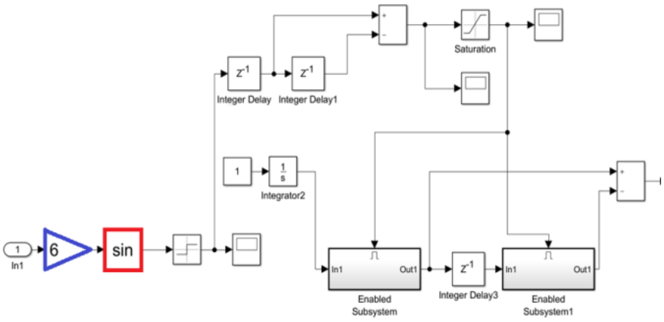

Fig. 4. **Engine shaft angular velocity measurement subsystem**
Source: **compiled by the authors**

At nominal characteristics and loads, six sample pulse graphs were constructed, which was taken as a basis for further calculations. With the help of the next block (Fig. 5) there was a comparison of the characteristics obtained in real time with the standard (exemplary) [5]. Reproducing this process manually would take a huge amount of time to define, build and compare these characteristics, while the Matlab / Simulink software environment does this almost instantly at the start of the simulation.

Mathematically, this subsystem is described by formula (2), where N is the RMS value of the duration of the first 12 pulses of a certain degree of loading; k, a – values of base (standard) and test (real) pulses, respectively; i is the sequence number of the pulse.

$$N=\frac{\sqrt{\sum_{i=1}^{12}(k_i-a_i)^2}}{12}.\quad(2)$$

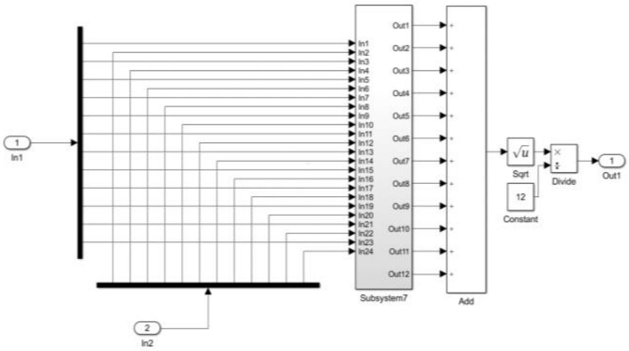

Fig. 5. **Subsystem for determining the sum of root mean square values of pulses**
Source: **compiled by the authors**

The next step, the system automatically builds a parabola to determine the extremum, which indicates the minimum degree of load on the cab. Comparison of the obtained values with six standard ones is also done with the help of a certain block presented in Fig. 6. The output parameter of this block is transmitted to the part of the controller responsible for calculating the braking start time.

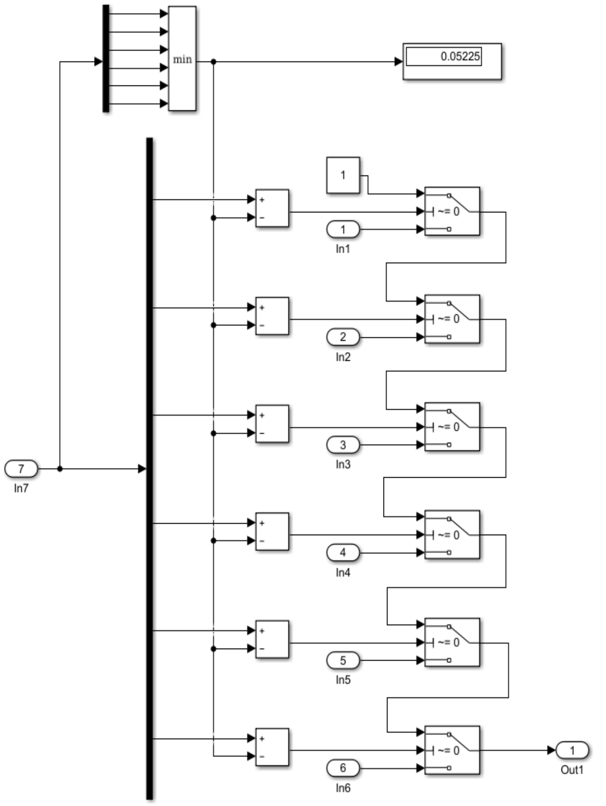

Fig. 6. **Subsystem for determining the actual degree of loading**
Source: **compiled by the authors**

Based on the experiments on the mathematical model, it was found that the developed method of determining the loading degree of the elevator car allows to increase the accuracy of its positioning to ± 5 mm (without using the method of positioning accuracy ±18 mm) due to changes in braking time [5].

According to subsequent studies, it was found that the supply voltage parameter also affects the calculation of the accuracy of the cab stop. To solve this problem, restrictions are applied for fluctuations in supply voltage within 10 % of the range according to the standards of Ukraine [30, 31].

For the study it was decided that it is necessary and sufficient to indicate the dependences of the influence on the accuracy of positioning the change of supply voltage for the following deviations from the nominal: 0 %, ± 2 %, ± 5 %, ± 8 %, ± 10 %, ± 12 %. The simulation results are presented in Fig. 7 show that the change in mains supply voltage affects the positioning accuracy. With increasing supply voltage, there is a shift of the entire positioning height line with a relatively constant step, which indicates some direct proportional dependence [32].

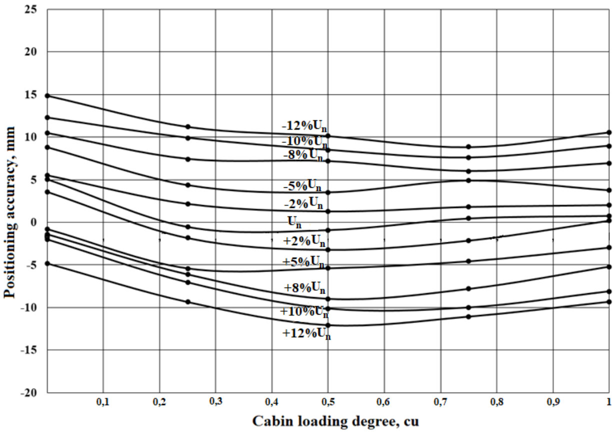

Fig. 7. **Dependence of positioning error on the supply voltage value using the identification method**

Source: **compiled by the authors**

From the obtained graphs it is seen that when the supply voltage changes, the identification method is not effective enough. However, when finding the dependences of the influence of supply voltage on the calculations, it is possible to adjust the positioning accuracy in order to reduce the stopping range. Thus, thanks to computer modeling, it is possible to investigate complex electromechanical processes, saving money, time and experiments. The speed of experiments and their unlimited time is a big advantage over physical testing, but not perfect.

CONCLUSIONS

1. Given the high cost of frequency-controlled asynchronous systems and the presence of a large number of already commissioned relay-contactor circuits (over 70 % in Ukraine), it is important to find budget options for drive control systems.

2. Computer simulation of the electromechanical system of a two-speed elevator allows studying the effect of changes in the value of the supply voltage, saving time and money on experiments.

3. In the simulation of the elevator EMC, this is presented in a simplified form in the form of a single-mass system, the influence of the supply voltage value on the calculation of the degree of loading of the cabin, which increases the positioning error.

4. As a result of experiments on a computer model of the elevator in Matlab / Simulink environment, it was found that when the mains voltage deviates from the nominal 380 V within ± 5 % of the elevator control system works with high accuracy. The calculated positioning accuracy meets the European requirements of EN 81-20: 2014, which indicates a permissible stop error of ± 10 mm. It should be noted that for loads over 25 %, all calculations are within the allowable range of ± 10 mm within the voltage range of the grid ± 10 % of the nominal. Therefore, we can say that this method of calculating the degree of loading of the cabin is better to use with small changes in mains voltage within ±5 %.

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Комп'ютерне моделювання електромеханічної системи двошвидкісного ліфта

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АНОТАЦІЯ

Сьогодні ліфтове виробництво в Україні потребує інноваційних рішень та змін, бо більшість обладнання, що знаходиться в експлуатації, побудовано та змонтовано ще у 70-80-х роках минулого століття. Зважаючи на високу ціну нових лебідок, що керуються частотними перетворювачами та складність обслуговування, альтернативним варіантом залишається пошук модернізації та вдосконалення існуючих ліфтових лебідок. Не менш важливим етапом експлуатації є діагностика. Своєчасне виявлення пошкоджень та прогнозування майбутніх відмов дозволяють забезпечити якісну роботу протягом усього терміну експлуатації, а також зменшити витрати бюджетних коштів на складні ремонти. Комп'ютерне моделювання у сучасному світі відіграє важливу роль як під час проєктування нового ліфта, так і протягом експлуатації. Завдяки досить простим та зрозумілим програмам є можливість відтворити не тільки стандартні режиму роботи механізмів, а й виконати розрахунки майбутніх можливих несправностей. Використання візуалізації полегшує сприйняття інформації для операторів, інженерів та інших користувачів, причетних до цього. У роботі представлено комп'ютерна модель двошвидкісного ліфта з асинхронним двигуном та редукторною лебідкою. Для досліджень використано програмне забезпечення Matlab / Simulink, яке є інтуїтивним у використанні та, у повному сенсі цього слова, інформативним. Побудована модель ліфта має зворотній зв'язок по розрахованому завантаженню кабіни. Останнє визначається з перехідних процесів під час пуску двигуна та впливає на точність позиціювання при зупинці. Знайдено залежності впливу ступеня завантаження кабіни на точність позиціювання. На другому етапі додано параметр напруги живлення мережі. Зміна цього параметра в межах ±10 % вплинула на попередні розрахунки ступеня завантаження та погіршило точність майже втричі. При цьому більшість показників (75 %) відповідають вимогам міжнародних стандартів EN 81-20: 2014 з похибкою позиціювання у діапазоні ±10 мм. У подальших дослідженнях планується використання отриманих результатів для зменшення чутливості алгоритму розрахунку ступеня завантаження кабіни до зміни напруги живлення та забезпечення необхідної точності позиціювання у всьому діапазоні навантаження кабіни при зміні напруги живлення ±10 %.

Ключові слова: комп'ютерне моделювання; діагностика; автоматизовані системи керування; двошвидкісний ліфт; метод ідентифікації; точність позиціювання

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