

MODERN GEARLESS ELEVATOR ELECTRIC DRIVE WITH BIINDUCTOR COMUTATORLESS ENGINE

Andriy BOYKO, Olexandr BESARAB, Yaroslav SOKOLOV

Electromechanics and Energy Institute, Odessa National Polytechnic University,
Shevchenko av. 1, UA-65044 Odessa, Ukraine

Tel: +38 048 705 85 81, Fax: +38 048 705 84 23, Email: andriy.boyko.56@mail.ru

Abstract: *Technical analysis of the requirements for drive motors and traction sheaves of elevator gearless winches was carried out. The most of technical solutions, which are positioned as innovative and facilitated the requirements for minimum engine speed, can be considered as unsatisfactory. The workability of bi-inductor type low-speed electric drive with rotor without hanks was considered. The features of innovation drive construction and main performance indicators were described. The basic design data of bi-inductor drives for several speeds of the elevator cabin were formed. The recommendations about the choice of appropriate speed of elevator winch and diameters of traction sheave were proposed. The synthesis of control system of elevator electric drive was carried out and the electric modes of its operation were explored by use the physical model and method of mathematical modeling. The basic advantages of offered gearless elevator electric drive were outlined.*

Key words: *Elevator, Winch, Gearless machine, Noncollector motor, Control system, Electric drive.*

1. Introduction

The lift industry is a powerful part of the global technology and economy, which reflects one of the most important features of modern civilization due to its importance. The main function of all passenger elevators is to provide transportation in the vertical plane in the buildings and different purpose constructions. They not only facilitate the daily physical movement of people, but quite often they are just one way of such movement. The total daily traffic volume in large cities exceeds the volume which is carried out by all kinds of public transport [1]. At the turn of the last two centuries, the qualitative leap occurred in the construction of lifts, as well as in almost all areas of technology, due to the achievements in mechanics, electrical mechanics, power mechanics and microelectronics, mechatronics. However, if we talk about the elevators, which have

been installed in buildings from seventieth to early nineteenth, it is necessary to admit their full moral obsolescence and significant physical deterioration. Taking into account that the expected useful life of lift is not more than 25 years, at least 50 - 60% of more than 70,000 passenger elevators in Ukraine have already worked this period [2]. Thus, we can expect their mass termination over this decade. While the yearly production of elevators in Ukraine is unlikely not exceed 1,000 elevators, throughout a year the 4,000 - 5,000 elevators must be replaced. In consideration of the necessity of elevators mass replacement in this decade and the volume of possible export, the yearly volume of elevators production should be much higher. Until recently the artificial extension of operating life and replacement of individual items of equipment were practiced as necessary measures that only worsen their technical backwardness and doesn't facilitate the quality and reliability of their exploitation. The problem of the passenger elevators replacement in Ukraine has long evolved from technical and economic to social. It should be emphasized that the problem of replacing old elevators by new electric drives (ED) exists not only in Ukraine. There are more than two million such elevators in Europe [2]. Most of them have capacity up to 1000 kg and speed up to 1.6 m / s and were installed in high-rise buildings as well as in Ukraine and [3]. It is needed to replace at least 800 thousand elevators in Eastern Europe. It would be very farsighted, if after its own problems solving, Ukraine could offer the experience and the relevant technical solutions to global market.

2. Problem Statement

The modern trend of electric drives development is the transition from gear to gearless constructions and the use of controlled systems. The vast majority of researchers work in this trend today [2, 4]. However,

sometimes the problems occur during the synthesis and exploitation of new type gearless winches and these problems are not always publicized by developers and manufacturers. One of the main and fundamental problems is the necessary of having the driving motors of winches which meet requirements [5]. Scientific analysis of a number of modern developments showed that many new types of electric drives with satisfactory dynamic and mass-dimensional indexes have the increased power consumption. Thus, the wide variation of reduced speed of drive motors results in significant deterioration of the electric drives energy efficiency, especially in the 1 - 1.6 m/s speed range of cabin movement. The usage of high-speed serial engines in the lower speed range results in significant reduction of energy performance, which substantially discredits the idea of gearless elevator winches usage. The second way is the use of low-speed drive motors, but there are no serial low-speed drive motors, which would fully satisfy the requirements. Therefore, the question of low-speed drive motors development and implementation are currently important [1, 5]. At the same time, the developers widely use the technical solutions [3], which are positioned as innovative and much ease the requirements to minimum engine speed, but most of them cannot be considered as satisfactory, for example:

- increase of polypast multiplicity results in increase of relevant blocks number, and this accordingly reduces the reliability and complicates the installation of the elevator, increases the wear of cables, reduces the efficiency of the cable transmission, limits the height of lifting of the cabin, leads to uneven tension of cables, increases the load on the guides, causing wearing and increase of the mechanical losses;

- renunciation of balances leads to significant increase of the installed power of engine of winch, even in comparison with the power of traditional two-speed asynchronous engine in the same conditions and modes of operation;

- increasing of the length of the cable transmission with constant cross-section leads to large displays of flexibility, which is expressed in high elastic vibrations of lifting gear and reduction of positioning accuracy of cabin.

3. Materials and methods

The gearless electric drive of direct current with rotor without hank was developed at the Institute of Electromechanics and Energy Consumption of Odessa

National Polytechnic University (Fig. 1) [6]. The usage of this gearless electric drive can help to solve the problem of the synthesis of new types gearless electric drives.

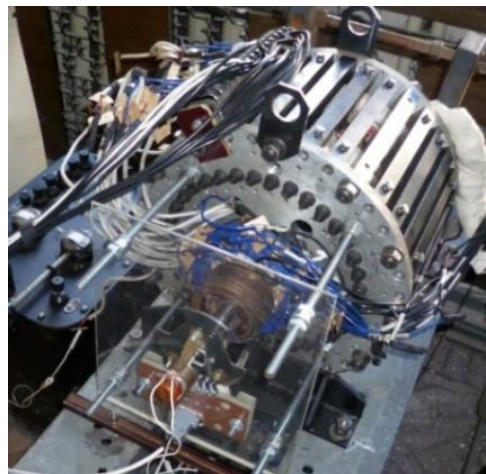


Fig. 1. General view of a prototype.

This engine consists of the rotor of mechanical or cylindrical type and stator, which have no general clamp. Rotor of end BNCDC (Fig. 2a) is some ferromagnetic poles 1, which are fixed on non-magnetic disc 2. Stator (Fig. 2b) consists of the series of individual unconnected ferromagnetic elements (battlements) 3, fixed on non-magnetic end shield 4. The toroidal coil of winding of exertion 5 is on the inner surface of the stator. The battlements 3 form battlement zones, in intervals (slots) of which conductors of winding of anchor are established 6 [6].

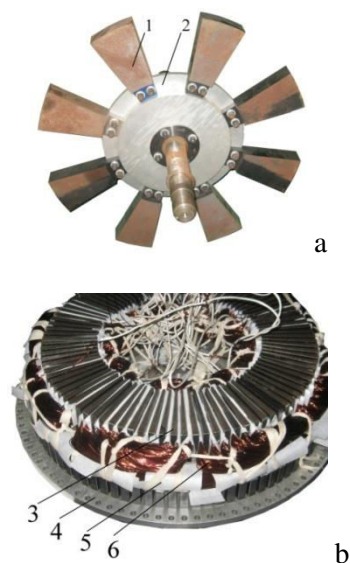


Fig. 2 The exterior of the rotor (a) and stator BNCDC (b)

The minimum configuration (Fig. 2b) of BNCDC consists of two fixed stators, connected with transverse ferromagnetic rods 7, between which rotor rotates, this rotor is separated from stators by operating air gap 8. The closed magnetic circle of drive is formed by the battlements 3, transverse rods 7 and poles 1, which are separated from the battlements by operating air gap 8. Such constructive decision allows next [7]: to significantly reduce reaction of an anchor and to bring the reloading capacity for current $K_i = I_{add} / I_n$ to 5 - 7, because the battlements do not have common yoke and unrelated magnetically; to reduce (to 30%) the costs of winding copper due to lack of additional poles and compensatory windings; to significantly improve the conditions of heat sink through structural gaps between the rods of stator; to improve the energy performance of the engine [6]. The weight of the rotor of this drive is in 3 - 5 times smaller than the weight of classic drive, and the moment of inertia proportionally reduces. Herewith, the speed of engine increases in 5 - 7 times, and, thus, the speed of electric also increases. The energy losses in BNCDC in transient conditions are lower than in the classic DC motor at such reducing of the moment of rotor inertia. This construction provides a modular approach of their production in various capacities by sequential alternation of disk rotor and the module of an anchor. If the permanent magnets, which alternate with ferromagnetic poles, were installed at the rotor (use the combined exertion), the capacity of BNCDC increases twice under the constant weight-size parameters [7]. All current winding in the proposed electric drive is placed on the fixed stator. Light disc rotor of mechanical or cylindrical type, separated from the stator by an air gap, is characterized by small size and lowered inertia. The stator slots are open on both sides and this makes it possible to significantly improve the heat dissipation due to the direct contact of the external environment with the active part of the engine. Such engine structure permits to increase the projected engine power rating at fixed geometry via increase of the current density or linear current load and thereby increasing the heat factor AI.

The calculations, obtained during the synthesis of gearless winches parameters, defined the design data of direct-current driving bi-inductor engines with end type without hanks rotor with narrowing from permanent magnets (see Table 1). The calculated moment is equivalent with heating for extended operation mode S1. The drive of winch must develop

the same moments both as by heating and by overload for all speeds of cabin under the reconstruction of optimal chart [8].

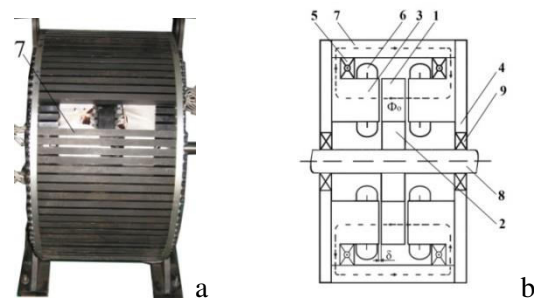


Fig. 3. Exterior of BNCDC (a); look of BNCDC in section (b)

Ideally, the engine weight and size will depend only on a given moment, and will not depend on the specified speed with maintain of optimal loads of active part of the engine. In fact, the weight and dimensions of the engine considerably increase with the significant reduction of the specified speed. The criteria of admissibility of winches low-speed drives, which are possible to use, are next: their weight is equal to or less than the mass of the basic two-speed asynchronous drives; coefficient of efficiency is bigger than efficiency of equivalent two-speed drive and worm gear reducer. Similarly, in further studies, while designing and choosing of drives of winches it seems a promising opportunity to consider a compromise to consider as the main parameter not capacity but moment that will allow using a high-speed drive [7].

Using this approach, it should be paid attention to the required range of the speed control, safety of exploitation of passenger elevator and energy performance of lifting gear. Also, during the transition to gearless winches, one of the problems is the coordination of the drive speed with the diameter of traction sheave. Taking into account the requirements for the implementation of the electric drive, it is desirable to have as much bigger speed as possible, but the bigger the speed of engine, the less diameter of sheave is needed.

Diameter of sheave cannot be less than a certain critical value which is related to the requirements to wear of ropes and removing their slipping [1]. For example, in the Table 2, considering the normal range of synchronous speed of electrical machines, necessary numbers of drive poles and diameters of traction sheave for polyspast suspension of cabin with the speed of the cab of 1.6 m/s are presented.

Table 1. Project data of the lift bi-inductor drives of direct current with rotor without hanks.

Parameters	Speed of cabin					
	1.0 m/s		1.6 m/s		2.0 m/s	
	without pol.	with pol.	without pol.	with pol.	without pol.	with pol.
Nominal speed, l/c	4.2	8.5	6.8	13.5	8.4	16.8
Nominal moment, N·m	835	425	911	460	1032	532
Nominal capacity, Wt	3507	3613	6195	6210	8669	8938
Nominal coefficient of efficiency, %	79	83	81	85	86	88
The moment of inertia of rotor, kg·m ²	0.270	0.104	0.320	0.120	0.350	0.143
Dimensions (length×diameter), m	0.38×0.46	0.35×0.38	0.38×0.46	0.38×0.38	0.38×0.49	0.41×0.39
Mass, kg	246	194	297	223	362	281

Table 2. Speed range of the winch drive and the diameters of the traction sheave.

Recommended revo	100	125	150	160	187	250	300	375	500	600
speed range 1/s	10.5	13.1	15.7	16.9	19.7	26.2	31.5	39.4	52.5	63
Number of poles, s.n.	60	48	40	36	32	24	20	16	12	10
Diameter of sheave, m	0.61	0.49	0.41	0.38	0.33	0.24	0.20	0.16	0.12	0.10

From the presented range of parameters of gearless winches, we can alternatively recommend a compromise of the drive with 40 poles and the sheave which has diameter of 0.41 m.

Electric drive of gearless elevator hoisting mechanism consists of winch, electrical power part and control system. Its functional diagram is shown at Fig. 4. The elements included in electric power part: three-phase uncontrolled rectifier (B); electric filter (F) with a controlled digit key; load-bearing module (LBM), which is assembled with 12-phase bridging IGBT transistor scheme that allows providing of commutation of the drive windings and its control through the bipolar pulse-duration modulation [6]. The winch has a mechanical structural component, the main elements of which are the traction sheave and slow commutatorless bi-inductor drive of direct current with rotor without hanks.

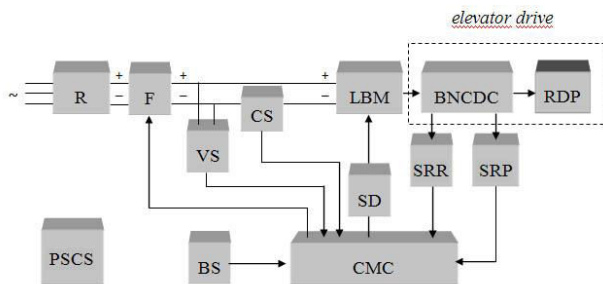


Fig. 4. Functional diagram of gearless lift electric drive.

The control system is consist of: current sensor (CS) and voltage sensor (VS) –the integrated sensors of parameters which operate on the basis of the Hall effect; Sensor Rotor Rate(SRR) - encoder (transducer of the angular displacement), which converts the rotation angle of the shaft of electric drive into electrical signals and generates a serial digital pulse code containing information on the current angle of the rotor; Sensor Rotor Position (SRP) - an optical sensor which is designed to obtain information about the state of the rotor BNCDC at any time; block of stimulus (BS), which is required for the formation of the managing signals, which determine the conditions and operating mode of winch; signals decoder (SD), which is based on a programmable logic integrated circuit that performs the functions of decoding signals from the optical Sensor Rotor Position (SRP) and Sensor Rotor Rate (SRR); control microcontroller (CMC), on the discrete and analog inputs of which the signals come from feedback sensors. The controller of the company ATMEL of ATmega32 type is used as managing microcontroller, which contains PWM modulator and three-flow control system and module of calculation of the speed of the digital encoder. Output PWM - signal is provided through signals decoder (SD) to control inputs of intellectual load-bearing module (LBM). PSCS - power supply of control system. Elements of protection, alarm and other assistive devices are not shown in order to simplify the analysis of the structure of the system.

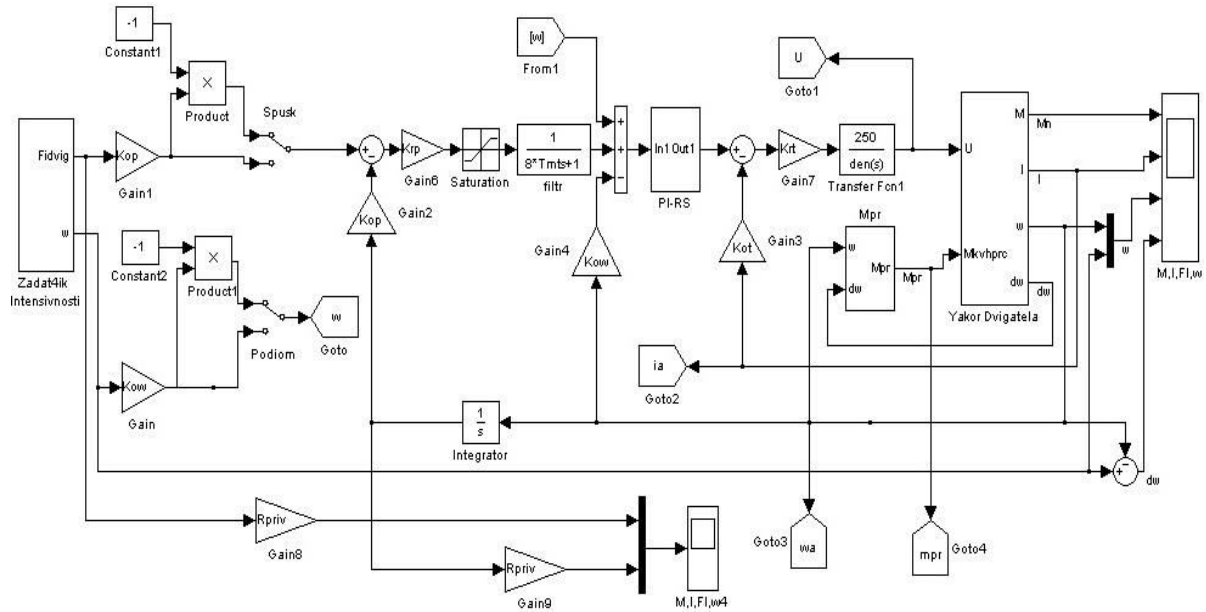


Fig. 5. Diagram of model of gearless elevator hoist with the control system in Simulink Matlab

Regulators of three-flow system of subordinate management with DPT as follows: current controller - relay, speed controller – proportional and integral (PI), set to symmetrical optimum, position regulator - proportional (P), set to the modular optimum [9]. The transfer functions of regulators are below. Current regulator:

$$H_{RC}(p) = \frac{1}{K_{SC}} \quad (1)$$

where K_{SC} – the coefficient of current sensor.

Rate regulator:

$$H_{RN}(p) = \frac{\hat{E}_{SC} \cdot J_{\Sigma}}{4 \cdot T_{mu} p \cdot \tilde{N} \cdot K_{SS}} \cdot \frac{(8 \cdot T_{mu} \delta + 1)}{8 \cdot T_{mu}} \quad (2)$$

where K_{SRR} – the coefficient of sensor of speed; C – coefficient; J_{Σ} – total moment of inertia; T_{mu} – noncompensated time constant.

Position regulator:

$$H_{RI}(p) = \frac{\hat{E}_{AN}}{16 \cdot T_{mu} \cdot K_{AI}}, \quad (3)$$

where K_{SP} – coefficient of sensor of position.

A filter with transfer function is used to compensate for unwanted exposure of time constant on the inlet of speed regulator

$$H_F(p) = \frac{1}{8 \cdot T_{mu} + 1} \quad (4)$$

4. Research results

Study of operating of gearless lift electric drive was performed by using a physical model and method of mathematical modeling (Fig. 5).

Both up and down moving of cabins were considered during analyzing of the operating modes. The cage of elevator is held stationary by the disk brake during a stop at the floor. The landing of passengers occurs during a stop of the cabin of elevator on the floor. The process of removing of the brakes occurs while turning on the electric drive before moving of the cabin of elevator up (down), which results in the process of electrical maintenance of the cabin by moment of the drive. After complete removal of the brakes the drive is in the short circuit mode and it waits for the command to start. While receiving the command to start, the cabin starts moving on a given path with the given restriction of spurt and acceleration with a maximum constant speed (Fig. 6).

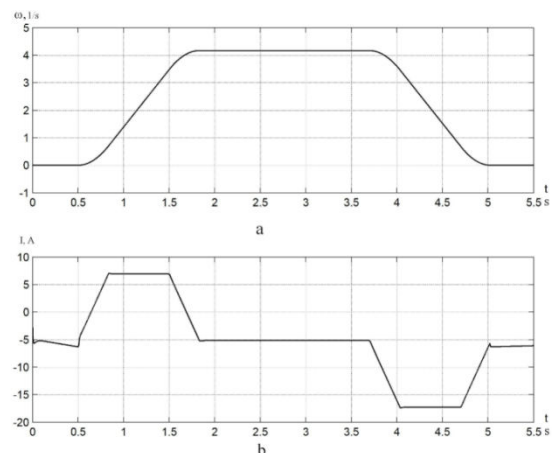


Fig. 6. Diagram of speed (a) and current (b) while moving of the cabin with current load of 80 kg

At the driving up to the set floor there is a process of the inhibition at the set trajectory with the restriction of dynamic movement parameters of the elevator cabin. After stopping electric drive works in the mode of electrical maintenance of the cabin which is needed for sure imposition of brake, and only then it turned off. If we use control electric drive in the mode of exact stop, there is no need to use sensor of accurate stop because the system is closed, and it works out set trajectory with high precision. The regime of electric maintenance of the cabin by the operating of electric drive occurs within 0.5 s, which is sufficient for safe removal and imposing brakes [10]. Fig. 5 shows that due to using of three-flow subordinate management system, the opportunity is provided to precise creation of given trajectory of the movement of the cabin and exact stop by BNCDC, which is performed on a certain floor without additional operations of approach to a given point. The movement is performed according to the calculated trajectory with restriction of given speed at the level of nominal, the acceleration - up to 1 m/s^2 and spurt - to 3 m/C^3 , which in this case accords to the angular values $\xi = 4.17 \text{ 1/s}^2$ and $\rho = 12.5 \text{ 1/C}^3$. These parameters fulfill the conditions of comfortable movement of passengers. The calculating form of graphics of speed is trapezoidal with set restrictions of spurt. Experimental characteristics of movement and speed of electric drive with BNCDC that were taken with the physical model are shown in Fig. 7 and 8. The difference between the experimental data and simulation results do not exceed 7% in static and 15% in dynamic modes.

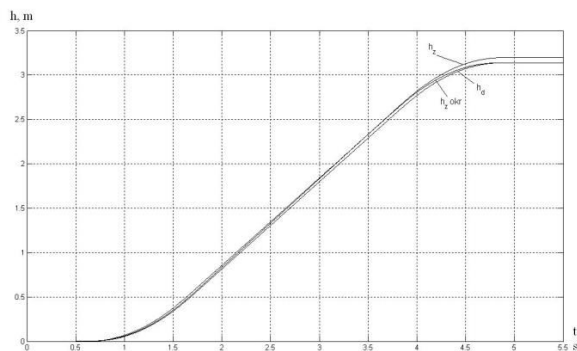


Fig. 7. Diagram of the cabin movement while setting management system: 1- considering fractional part; 2 - part of a whole; 3 – at the output of the drive at integer setting

The 8-bit PWM was used to generate PWM sequence, so the setting of the duty cycle consists of integers from 0 to 255. In the received calculated values the setting of the duty cycle was used considering fractional and with rounding to integer values.

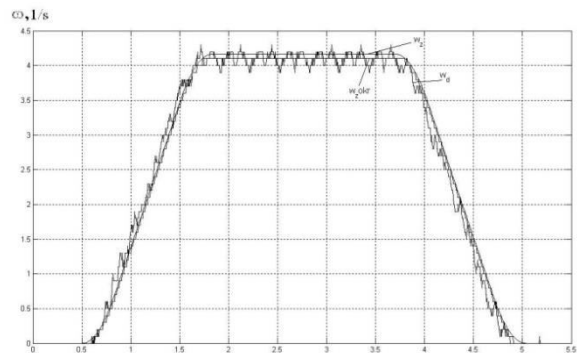


Fig. 8. Angular speed variation diagram of winch while the cabin moves with load of 80 kg at the setting of the management system: 1- considering fractional part; 2 - part of a whole; 3 – at the output BNCDC at integer setting

The diagram of speed 1 accords to setting by the fractional while driving up on one floor (3.2 m). The passed path1 in this case is 3.1395 m, which is less than necessary on 6 sm. The result is that the setting was given to the input of the speed regulator in the form of $4.1 \text{ 1/s} \cdot 10 = 41$ discrete instead of 4.16 1/s (max setting for S-characteristic). Using the value of setting with integer number, the error of passed path is 0.12 mm; the speed diagram is labeled as 2. The angular speed and passed path at the output of drive at integer setting are indicated as 3. It is necessary to introduce a correction factor to increase the capacity PWM to 10 bit in order to compensate the difference between the setting of the whole and fractional part.

5. Conclusions

1. The possibility of synthesis and usage of gearless electric drive with innovative commutatorless bi-inductor electric drive of direct current with rotor without hanks were proved. The proposed electric drive, due to design features of low-speed drive, has mass, dimensions and inertia, which are much lower than in traditional basic version, while having other similar parameters.

2. The synthesized system of management of gearless elevator electric drive ensures accurate creation of given optimum chart and exact stop of the cabin, which is performed at the required floor without additional operations at the approach to the set point. The movement is implemented according to the calculated trajectory with appropriate restrictions of set speed at nominal level, the acceleration is to 1 m/s^2 and spurt is to 3 m/C^3 , which accords to the conditions of comfortable movement of passengers. The maximum error of moving of the cabin at the setting is not exceeding 4.52 mm.

References

- [1] Adler, R. R.: *Vertical transportation for buildings*. Welley, New-York, 1990.
- [2] Andryushchenko, O.A., Boyko, A.A.: *Improving the technical level of passenger elevators in Ukraine, evolution or revolution?* In: *Economist*, No. 8, August 2011, p. 75-79, Moscow.
- [3] *Elevators without machine room KONE Monospace: Corporation "KONE"* (electronic resource). Retrieved from: <http://cdn.kone.com/www.kone.ua/ru/Images/brochure-monospace-500.pdf> (date of access 24.02.2016).
- [4] Makarov, L.N.: *Modern electric drive of high-speed elevators of increased comfort*. In: *Electrical engineering*, No. 5, 2006. p. 42-46, Moscow.
- [5] Archangelskiy, G.G.: *Modern trends and prospects of development of the construction of elevators*. In: *Stroyprofil*, No. 7, 2008. p. 94-96, St. Petersburg.
- [6] Andryushchenko, O.A., Bulgar, V.V., Boyko, A.O., Ivlev, D.A., Yakovlev, O.V., Kosenkov V.D.: Patent of Ukraine № 104943, IPC (2014), NO2K 29/06. Electric machine of bi-inductor type. In: –a201211580, appl. 08.10.2012, publ. 03.25.2014, Bull. No. 6.
- [7] Boyko, A.O., Akchebash, N.V.: *The features of application of commutatorless electric drive of direct current in the mechanisms of lifting of passenger elevators*. In: *Electrical and technical and computer systems*, Vol. 11, No. 87, 2013, p. 22-28, Kyiv.
- [8] Besarab, A.N., Sokolov, Y.A.: *Hardware and software system for the analysis of indicators of quality of electric energy*. In: *Electrical machinery and electrical equipment*, Vol. 74, 2009, p. 53-57, Kyiv.
- [9] Boyko, A.A., Boyko, N.A., Besarab, A.A.: *The considering of influence of elastic mechanical gears on optimum chart of movement of passenger elevators*. In: *Electromechanical and electro-saving systems*, Vol. 1, No. 11, 2015, p. 23-29, Kremenichuk.
- [10] Jong, J., Hakala, H.: *The advantage of PMSM Elevator Tehnology in High Rise Building, Proccesing of Elevcon*. In: IAEE, 2000. Retrieved from: http://cdn.kone.com/major_projects.kone.com/Images/elevcon2000-pmsm.pdf?v=3