UDC 621.313.29:692.66

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FEATURES OF PARAMETER FORMATION WHEN COMPARING THE EFFICIENCY OF PASSENGER ELEVATORS ELECTRIC DRIVES

А. Бойко, А. Савельєв, І. Климчук, Д. Ігнатенко. **Особливості формування параметрів при порівнянні ефективності електроприводів пасажирських ліфтів.** Сучасний стан ліфтового господарства у житлово-комунальному секторі являє собою доволі важливу актуальну проблему. Більшість машин наявного парку вже відпрацювали свій ресурс на 60 % та більше. Проведено аналіз сучасного стану парку пасажирських ліфтів, як в житлових будинках так і в спорудах різного типу комунально-житлового сектору. Виявлено, що висновки щодо значного підвищення енергоефективності електроприводів нових типів часто робляться на основі їх порівняння з технологічно застарілими лебідками з двошвидкісними двигунами та черв'ячними редукторами. Визначено, що технічні рішення реалізуються за рахунок ряду компромісів, а саме: збільшення кратності поліспаста; відмова від противаги; збільшена довжина канатів при малій площі перерізу. Доведено, що для проведення об'єктивного техніко-економічного порівняння ліфтових електроприводів в умовах нестачі даних про їх конструктивні характеристики необхідне коректне застосування як нових, так і вже існуючих методів оцінки. Показано - перед проведенням техніко-економічного аналізу обов'язковим є збір статистичних даних щодо експлуатації ліфта та його основних систем. Усі параметри, що підлягають аналізу, поділяються на загальні, параметри підйомного механізму та електроприводу. З практичного досвіду показано – техніко-економічні показники ліфтового електроприводу значною мірою залежать від наявності або відсутності редуктора, типу лебідки та використовуваної системи керування, а також від режимів роботи цих елементів. На основі обраних математичних моделей роботи ліфту у визначних умовах отримано оптимальні діаграми руху кабіни ліфта при різних відстанях її переміщення, а також розрахункові кінематичні схеми підйомних механізмів ліфтів із прямою підвіскою та з поліспастною підвіскою. Також визначено параметри елементів типової ліфтової підйомної установки та статичні зусилля на ободі канатоведучого шківа та моменти навантаження під час підйому залежно від номера зупинки. Отримані результати дослідження дозволяють надалі виділити основні варіант популярних ліфтових систем, які підлягають техніко-економічному порівнянню та відрізняються між собою конструкцією.

Ключові слова: пасажирські ліфти, енергоефективність приводів, електроприводи, енергоспоживання ліфтів

A. Boiko, A. Savieliev, I. Klymchuk, D. Ihnatenko. **Features of parameter formation when comparing the efficiency of passenger elevators electric drives.** The current situation in the elevator industry in the housing and communal sector is a rather important and urgent problem. Most of the machines in the existing fleet have already worked out their resource by 60% or more. There was conducted an analysis of the current state of the passenger elevator fleet, both in residential buildings and in various types buildings of the communal and residential sector. It was found that conclusions regarding a significant increase in the energy efficiency of new types electric drives are often made on the basis of their comparison with technologically outdated winches with two-speed motors and worm gearboxes. It was determined that technical solutions are implemented at the expense of several compromises, namely: increasing the multiplicity of the pulley block; abandoning the counterweight; increasing the length of the ropes with a small cross-sectional area. It was proved that for an objective technical and economic comparison of elevator electric drives when a lack of data on their design characteristics, the correct application of both new and existing assessment methods is necessary. It is shown that before conducting a feasibility study, it is necessary to collect statistical data on the operation of both the elevator properly and its main systems. All parameters subject to analysis are divided into general, parameters of the lifting mechanism and electric drive. From practical experience, it is shown that the technical and economic features of the elevator electric drive largely depend on the presence or absence of a reducer, the winch type and the control system used, as well as on these elements' operating modes. Based on the selected mathematical models of the elevator operation in specific conditions, optimal diagrams of the movement of at different distances of its movement were obtained, as well as calculated kinematic diagrams of the elevator car lifting mechanisms of elevators with direct suspension and with polyspast suspension. The parameters of the elements of a typical elevator lifting installation and static forces on the rim of the rope-driving pulley and load moments during lifting depending on the stop number were also determined. The obtained research results allow further identifying the main variants of popular elevator systems that are subject to technical and economic comparison and differ in design.

Keywords: passenger elevators, energy efficiency of drives, electric drives, energy consumption of elevators

1. Introduction

The main task of all passenger elevators is to provide transportation in the vertical plane in various purposes buildings and structures. They not only facilitate the daily physical movement of people, but sometimes are the only means of such movement. In large cities, elevators carry more passengers every day than all types of urban transport combined.

Elevators are classified according to many characteristics: purpose, load capacity, speed, design of the lifting mechanism, level of automation and comfort. In modern multi-storey and administrative

DOI: 10.15276/opu.1.71.2025.15

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

buildings of Ukraine, built since the mid-90s, the most often installed are elevators from well-known foreign companies which are also engaged in their maintenance. Such elevators meet world standards, and their quality is constantly being improved.

However, elevators in mass-built buildings of the 70s, 80s and early 90s are morally and physically outdated. Planned replacement or modernization of these elevators' electric drives (EDs) has practically not been carried out since then, which only worsens the situation. Given that the estimated service life of an elevator is no more than 25 years, among more than 100 thousand passenger elevators in Ukraine, at least 60…70% have already served this term [1].

Thus, the development of the passenger elevator fleet in Ukraine is an urgent economic, social and technical problem of the state level.

2. Analysis of literary data and formulation of the problem

Most researchers note the fact that leading manufacturers of passenger elevators hide basic technical information about their developments, limiting themselves to general advertising descriptions [1–4, 7, 8]. Information from technical catalogs of elevator manufacturing companies is characterized by the absence of even basic indicators of electric drives, such as the drive motor speed or its efficiency factor (EFC) [3, 8]. At the same time, technical parameters can be provided in full, but in a very fragmented form [2]. This also renders impossible to objectively compare the efficiency of elevator electric drives of different types and manufacturers.

Conclusions about a significant increase in energy efficiency of new types of electric drives are often made on the basis of their comparison with technologically outdated winches with two-speed motors and worm gearboxes [3]. At the same time, when comparing innovative gearless elevator winches with gear winches of a new design, which are controlled by frequency converters, these conclusions can be diametrically opposed [4].

Technical solutions are implemented through a number of compromises, most of which are considered controversial:

1. **Increasing the pulley block multiplicity** to reduce the required speed of the winch motor leads to an increase in the number of diverter blocks [5]. This complicates the installation of the elevator, increases the ropes wear, reduces the efficiency of the rope transmission, and limits the height of the car lift. It also causes uneven tension of the ropes and skewing of the car, which increases the load on the guides, causing their wear and increased mechanical losses [6];

2. **The counterweight forces rejection** involves a significant increase in the installed power of the motor, even in comparison with the common two-speed inductors motor (IM), which leads to increased power losses in static and dynamic operating modes [7, 8];

3. **The increased length of the ropes with a small cross-sectional area** leads to significant manifestations of flexibility, which can cause car oscillations and an increase in the stopping error [9]. This is compensated by the recommended car lift heights of no more than 20…25 m [10].

Comparison of weight and dimensions of electric drives is usually carried out without taking into account mounting blocks and lifting mechanism structures, which is incorrect [11, 12].

3. The purpose and objectives of the research

Modern passenger elevators are equipped with various types electric drives, each having specific characteristics that determine their efficiency depending on the operating conditions. However, existing evaluation methods often do not take into account a comprehensive analysis of elevator systems and their main parameters, such as [4, 5]:

– energy consumption in different operating modes;

– dynamic characteristics of movement;

– efficiency of the elevator system;

– the impact of load and operating mode on the equipment durability.

The need to form objective criteria for comparing electric drives is due to the need to optimize the elevator equipment operation, to reduce energy consumption and to increase operational reliability.

For conducting an objective technical and economic comparison of elevator electric drives in the absence of data on their design characteristics, it is necessary to correctly apply both new and existing evaluation methods.

One of these methods is the basic trip method, based on the introduction of the elevator car basic trip concept, and any arbitrary trips are subsequently reduced to an equivalent number of basic ones [13]. The complexity of using this method lies in the need to process and organize a large amount of initial operational parameters and their combinations (average number of starts per hour, trip length, cabin load).

This determines the given study purpose: to develop a methodology and justify approaches to the formation of parameters for a comparative analysis of the efficiency of passenger elevator electric drives. The study considers key parameters that affect the energy efficiency and operational characteristics of elevator electric drives of different types [3].

4. Methods of conducting research and processing experimental data

Before conducting the technical and economic analysis, it is mandatory to collect statistical data on the operation of the elevator and its main systems. This can be done both on an operating passenger elevator and using its mathematical or physical models. In this case, each parameter that affects the feasibility indicators is given a specific numerical value. If necessary, several values of one parameter are considered.

All parameters subject to analysis are divided into general, parameters of the lifting mechanism and electric drive. As practice shows, the technical and economic indicators of the elevator electric drive largely depend on the presence or absence of a gearbox, the type of winch and the control system used, as well as on the operating modes of these elements. Such an assumption allows reducing the number of general parameters to a logically justified minimum.

As an object of such study, it is advisable to choose passenger elevators of residential buildings with a height of up to 9…20 floors. This is relevant for the construction industry of Ukraine and allows taking into account almost the entire range of nominal cabin lifting speeds [1]. It is recommended to limit the nominal mass of the transported payload to the maximum operational value of 1600 kg [4].

All other coefficients, time intervals and other parameters describing the operating modes of any arbitrary elevator electric drive system should be taken in accordance with the regulatory operational requirements.

5. Results of experimental bench research

Nominal cabin capacity:

$$E_n = m_{\text{car}} / m_{\text{pas}}, \tag{1}$$

where: $m_{\text{pas}} = 80$ – average weight of one passenger, kg.

$$E_n = 1600 / 80 = 20 \text{ pas.}$$

Given that inter-storey transportation is rare in residential buildings, the estimated cabin capacity when moving up:

$$E_{c\,\text{up}} = \gamma_{\text{up}} \cdot E_n. \tag{2}$$

$$E_{c\,\text{up}} = 0.8 \cdot 20 = 16 \text{ pas.}$$

And when moving down:

$$E_{c\,\text{dn}} = \gamma_{\text{dn}} \cdot E_n \cdot, \tag{3}$$

$$E_{c\,\text{dn}} = 0.6 \cdot 20 = 12 \text{ pas. },$$

where: $\gamma_{\text{up}}, \gamma_{\text{dn}}$ – elevator cabin occupancy rates during ascent and descent, respectively [14]. Number of probable stops:

$$N_{\text{pr}} = N_1 - N_1 \left(\frac{N_1 - 1}{N_1} \right)^{E_c}, \tag{4}$$

where: N – number of floors in the building; $N_1 = N - 1$ – number of floors served by the elevator; E_c – estimated number of passengers.

During upward movement $N_{\text{pr up}} = 13$; During downward movement: $N_{\text{pr dn}} = 10$. The magnitude of the jerk should be discussed separately. As studies of elevator dynamics taking into account the elasticity of the ropes have shown, the jerk can increase by two times or more compared to the dynamics of a rigid system [8].

Therefore, the calculations assume a jerk value smaller than that recommended in the literature. The accepted calculated values of speed, acceleration, and jerk are summarized [5]. The choice of the

 ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

jerk value should be discussed separately. As shown by studies of elevator dynamics taking into account the elasticity of the ropes, the jerk can increase by two or more times compared to the dynamics of a rigid system [8]. Therefore, the calculations assume a jerk value smaller than that recommended in the literature. The accepted calculated values of speed, acceleration, and jerk are summarized in Table 1.

Table 1

Estimated values of the speed, acceleration and jerk of the elevator cabin

Maximum speed v_{max}, m/s	Maximum acceleration a_{max}, m/s^2	Calculated jerk r_k, m/s^3
1.5	1.5	3
2	2	3
2.8	2	3
4	2	3
6	2	3

The average distance of one trip during ascent is 9 m, and during descent it is 11.7 m. For the considered range of speeds, accelerations and jerks, depending on the distance of the trip, three types of optimal diagrams of the cabin movement can be expected in accordance with Fig. 1. The values of the motion parameters used in further calculations are given in Table 2. The total time of the cabin movement up and down consists of the movement time and the auxiliary time. The movement time, in turn, consists of the acceleration time t$_{ac}$, braking time t_{br} and the time of movement at a constant speed t_{con} during ascent or descent. It depends on the given value of the nominal speed of the elevator cabin (Table 2). Since the diagrams are symmetrical, the acceleration time is always equal to the braking time.

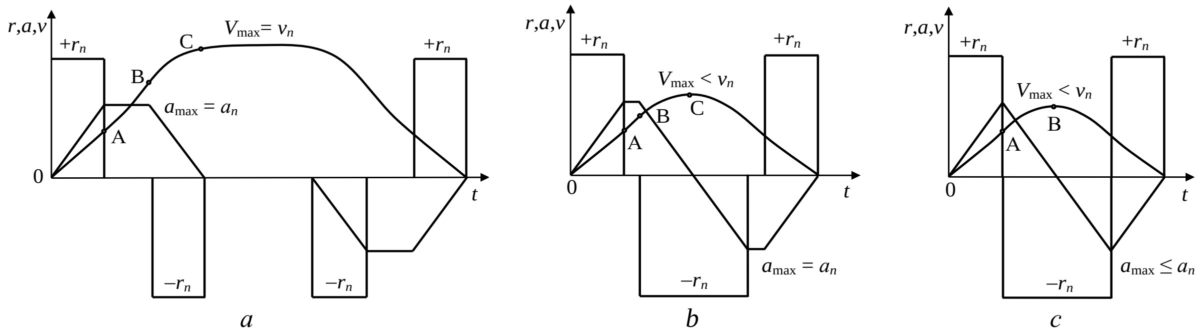


Fig. 1. Optimal diagrams of the elevator car movement at different distances of its movement: trapezoidal acceleration diagram (*a*); truncated trapezoidal acceleration diagram (*b*); triangular acceleration diagram (*c*)

Table 2

Elevator cabin motion parameters during travel over typical distances

Distances and cabin movement parameters	Specified nominal parameters and limitations					
	V_n, m/s	1.5	2	2.8	4	6
	a_n, m/s	1.5	2	2	2	2
	r_n, m/s^2	3	3	3	3	3
	Fig. 1*	*a*	*b*	*b*	*c*	*c*
1	*2*	*3*	*4*	*5*	*6*	*7*
1. Floor (3 m)	t_{ac}, s	1.5	1.6	1.6	1.6	1.6
	t_{con}, s	0.5	–	–	–	–
	t, s	3.5	3,2	3,2	3.2	3.2
	V_{max}, v/s	1.5	1.88	1.88	1.88	1.88
	a_{ave}, m/s	1	1.175	1.175	1.175	1.175
	Fig. 1*	*a*	*a*	*a*	*b*	*b*
2. Floors (6 m)	t_{ac}, s	1.5	1.67	2.07	2.09	2.09
	t_{con}, s	2.5	1.33	0.08	–	–
	t, s	5.5	4.67	4.22	4.18	4.18
	V_{max}, v/s	1.5	2	2.8	2.87	2.87
	a_{ave}, m/s	1	1.197	1.35	1.37	1.37
	Fig. 1*	*a*	*a*	*a*	*b*	*b*
3. Floors (average lifting distance 9 m)	t_{ac}, s	1.5	1.67	2.07	2.48	2.48
	t_{con}, s	4.5	2.83	1.15	–	–

1	*2*	*3*	*4*	*5*	*6*	*7*
	t, s	7.5	6.17	5.29	4.96	4.96
	V_{max}, v/s	1.5	2	2.8	3.64	3.64
	a_{ave}, m/s	1	1.197	1.35	1.47	1.47
	Fig. 1*	*a*	*a*	*a*	*a*	*b*
4. Floors (12 m)	t_{ac}, s	1.5	1.67	2.07	2.67	2.8
	t_{con}, s	6.5	4.33	2.22	0.335	-
	t, s	9.5	7.67	6.36	5.675	5.6
	V_{max}, v/s	1.5	2	2.8	4	4.29
	a_{ave}, m/s	1	1.197	1.35	1.49	1.53
	Fig. 1*	*a*	*a*	*a*	*a*	*b*
Average distance when descending 11.7 m	t_{ac}, s	1.5	1.67	2.07	2.67	2.77
	t_{con}, s	6.3	4.18	2.11	0.26	-
	t, s	9.3	7.52	6.25	5.6	5.54
	V_{max}, v/s	1.5	2	2.8	4	4.23
	a_{ave}, m/s	1	1.197	1.35	1.49	1.53
	a_{ave}, m/s	1	1.197	1.35	1.49	1.53

*type of motion diagram according to Fig. 1; t_{ac} – acceleration (start-up) time, s; t_{con} – time of movement at a constant speed, s; t – full time of movement, s; V_{max} – maximum cabin speed, m/s; a_{ave} – average cabin acceleration during start-up, m/s^2

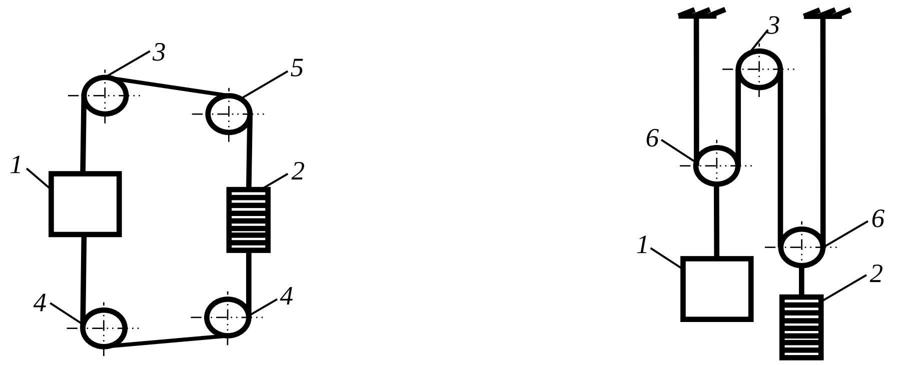
Auxiliary time includes the time of opening t_{op} and closing t_{cl} of the elevator car door, the time of passengers entry t_{en} and exit t_{ex}, the time of the car movement beginning t_{beg} and end t_{end}. The latter is spent on leveling the car floor level with the landing platform level, as well as on applying and removing the mechanical brake. Auxiliary time does not depend on the speed of the car movement. The following values are taken in the calculations: $t_{op} = t_{cl} = 1.5$ s; $t_{en} = t_{ex} = 1$ s; $t_{beg} = t_{end} = 0.5$ s.

Then full auxiliary time is [15]:

$$t_0 = (t_{op} + t_{cl} + t_{bed} + t_{end})(N_{pr\,up} + N_{pr\,dn}) + (t_{en} + t_{ex})(E_{c\,up} + E_{c\,dn}). \quad (5)$$

For the considered parameters, the auxiliary time is 148 s.

According to the design, elevators with gear and gearless electric drives are considered. The cabin suspension can be direct or polyspast Fig. 2.



a *b*

Fig. 2. Calculated kinematic diagrams of elevator lifting mechanisms with direct suspension (*a*) and with polyspast suspension (*b*): *1* – cabin; *2* – counterweight; *3* – rope-driving pulley (RDP); *4* – tensioning block of compensating ropes; *5* – branch block; *6* – suspension block

In the case of a geared version of the electric drive (ED), it is recommended to take the synchronous speed of inductor motors as the calculated speed, which is 1000…1500 rpm, and for high-speed DC motors – 600…750 rpm, depending on the motor power [16].

The linear speed of the elevator cabin V in m/s and the speed of the winch motor n_{mot} are related by the known ratio:

$$V = \pi i' n_{mot} \frac{1}{60}, \quad (6)$$

 ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

where: $i' = \dfrac{D_{\text{rdp}}}{i_{\text{tr}}}$ – equivalent gear ratio from engine to cab; D_{rdp} – diameter of the rope-driving pulley, m; i_{tr} – gear ratio of the winch transmission.

The equivalent gear ratio introduction allows preliminary calculations to be made without precise information about the diameter of the rope-driving pulley and the gear ratio of the reducer. Real gear ratios of reducers at a nominal speed $V_n \geq 1.5$ m/s are quite difficult to implement using worm gears [17]. In addition, the main property of the worm gear – self-braking – is not used in controlled systems in which the modes of "weighing" and precise stopping of the elevator car are used [6]. Therefore, the condition is accepted that the required values of gear ratios are implemented using cylindrical gear-boxes (planetary), which have an average efficiency of 90….95%. Data on the masses and moments of inertia of individual components of the lifting mechanism are given in Table. 3. Determination of static forces in the rope and moments on the rope-driving pulley of the winch is performed with the assumption that the change in the elevator car mass at stops occurs uniformly [18].

Table 3

Parameters of elements of a typical elevator lifting installation

Parameters	Conv. denot.	Value	Parameters	Conv. denot.	Value
General parameters			Tensioning block of compensating ropes		
Elevator load capacity	m_{lp}	1600 kg	diameter	D_{cr}	0.85 m
Mass of cabin	m_{c}	2500 kg	Inertia momentum	J_{cr}	16 kg·m^2
Mass of traction ropes	m_{lp}	1100 kg	Braking pulley		
Mass of compensation ropes	m_{cr}	990 kg	diameter D_{cr}	D_{bp}	0.6 m
Mass of suspension ropes	m_{sr}	330 kg	Speed limiter block		
Counterweight weight	m_{w}	3300 kg	diameter	D_{sl}	0.33 m
Rope-driving pulley			Inertia momentum	J_{sl}	5 kg·m^2
Diameter	$D_{r\,\text{dp}}$	0.68 m	Rope bending loss coefficient	–	0.02
Inertia momentum	$J_{r\,\text{dp}}$	13 kg·m^2			
Branch block					
Diameter	D_{b}	0.68 m	Inertia momentum	J_{b}	13 kg·m^2

$$\Delta m_\Sigma = \frac{m_\Sigma}{N_{\text{pr}}}. \tag{7}$$

When lifting [16]: $\Delta m_{\Sigma\,up} = \dfrac{1280}{13} = 98.5$ kg., when lowering: $\Delta m_{\Sigma\,\text{dn}} = \dfrac{960}{10} = 96$ kg.

Due to the close value of $\Delta m_{\Sigma\text{up}}$ and $\Delta m_{\Sigma\text{dn}}$, it is possible to obtain their average value $\Delta m_\Sigma = 98$ kg. Static forces at different cabin loadings during lifting [19]:

$$F_{\text{up}} = \left(m_s + m_{l,\text{cou}} - K \int_0^{N_{pr}-1} \Delta m_{\Sigma\,\text{up}} - m_{\text{cou}} \right) g. \tag{8}$$

When lowering:

$$F_{\text{dn}} = -\left(m_s + K \int_0^{N_{pr}-1} \Delta m_{\Sigma\,\text{dn}} - m_{\text{cou}} \right) g, \tag{9}$$

where: K – coefficient depending on the stop number; g – acceleration of gravity, m/s^2.

The zero stop number for lifting corresponds to the first floor, and for descending – to the last (fortieth). In this case, the signs of the forces F_{up} and F_{dn} reflect the engine operating mode ("+" – driving, "–" – braking). Static moments on the winch RDP in motor mode:

$$M_{s\,\text{mot}} = \frac{F_{\text{up(dn)}}}{2\eta_{\text{tr}} i'}, \tag{10}$$

where: η_{tr} – Efficiency of mechanical transmission (0.9…0.98 for gear cylindrical transmission and 0.98 for gearless transmission and hoisting mechanism with a pulley block) [20].

When the winch motor is operating in braking mode:

$$M_{s\ \text{br}} = \frac{F_i \eta_{\text{p}}}{2i'}. \tag{11}$$

Static forces on the RDP rim and load moments during lifting, depending on the stop number, are given in Table 4. Total induced moment of inertia:

$$J = \Sigma J_{\text{rot}} + \Sigma J_{\text{gr}}, \tag{12}$$

where: ΣJ_{rot} – the given moment of inertia of rotating parts, kg·m^2; ΣJ_{gr} – the given moment of inertia of gradually moving parts, kg·m^2:

$$\Sigma J_{\text{rot}} = (a+b+1)J_{\text{mot}} + \frac{J_{\text{rp}}}{i_{\text{tr}}^2} + \frac{J_{\text{b}}}{i_{\text{tr}}^2} + \frac{J_{\text{cr}}}{\left(\dfrac{D_{\text{cr}}}{D_{\text{rp}}} i_{\text{tr}}\right)^2} + \frac{J_{\text{sl}}}{\left(\dfrac{D_{\text{sl}}}{D_{\text{rp}}} i_{tr}\right)^2}, \tag{13}$$

where: $a = 0.25$ – coefficient that takes into account the inertia of the gearbox; $b = 0.5$ – coefficient that takes into account the inertia of the brake pulley; J_{rdp} – moment of inertia of the rope-driving pulley, kg·m^2; J_{b}, J_{cr}, J_{sl} – moments of inertia of the branch, tensioning and speed limiting blocks, respectively, kg·m^2:

$$\Sigma J_{\text{gr}} = \frac{1}{4}\left(\frac{D_{\text{rdp}}}{i_{\text{tr}}}\right)^2 (m_c + m_{\text{tr}} + m_{\text{cr}} + m_{\text{sr}} + m_{\text{w}} + m_{\text{ave}}), \tag{14}$$

where: m_c – cabin mass, kg; m_{tr}, m_{cr} – mass of traction and compensating ropes, kg; m_{sr} – weight of the suspension rope, kg; m_{w} – counterweight weight, kg; m_{ave} – weight with average cabin load during lifting and lowering, kg:

$$m_{\text{ave}} = \frac{m_{\text{ave up}} + m_{\text{ave dn}}}{4}. \tag{15}$$

Table 4

Static forces on the rope-driving pulley rim and load moments during lifting depending on the stop number

Stop number			0	1	2	3	4	5	6	7	8	9
effort (N)			4708	3747	2786	1825	863	–98	–1098	–2021	–2982	–3943
Momentum (Nm)	Geared winches (according to cabin speed (m/s))	1.5	$\frac{75}{100}$	$\frac{59}{79}$	$\frac{44}{59}$	$\frac{29}{39}$	$\frac{14}{19}$	$\frac{-2}{-3}$	$\frac{-14}{-19}$	$\frac{-26}{-35}$	$\frac{-38}{-51}$	$\frac{-51}{-68}$
		2.0	$\frac{100}{167}$	$\frac{80}{133}$	$\frac{59}{98}$	$\frac{39}{65}$	$\frac{18}{30}$	$\frac{-2}{-3}$	$\frac{-18}{-30}$	$\frac{-35}{-58}$	$\frac{-51}{-85}$	$\frac{-68}{-113}$
		2.8	$\frac{140}{233}$	$\frac{111}{185}$	$\frac{83}{138}$	$\frac{54}{90}$	$\frac{26}{43}$	$\frac{-3}{-5}$	$\frac{-32}{-53}$	$\frac{-60}{-100}$	$\frac{-89}{-148}$	$\frac{-117}{-195}$
		4.0	$\frac{200}{333}$	$\frac{159}{265}$	$\frac{118}{197}$	$\frac{77}{129}$	$\frac{37}{61}$	$\frac{-3}{-5}$	$\frac{-37}{61}$	$\frac{-70}{-116}$	$\frac{-103}{-171}$	$\frac{-136}{-226}$
		6.0	$\frac{301}{502}$	$\frac{239}{398}$	$\frac{178}{297}$	$\frac{117}{195}$	$\frac{55}{92}$	$\frac{-5}{-8}$	$\frac{-55}{-92}$	$\frac{-104}{-173}$	$\frac{-154}{-257}$	$\frac{-204}{-340}$
	Gearless electric drives with direct suspension		1633	1300	966	633	299	–33	–353	–673	–994	–1314
	Gearless electric drives with chain hoist suspension		817	650	483	317	150	–17	–177	–337	–497	–657

For the considered option:

ISSN 2076-2429 (print)
ISSN 2223-3814 (online)

$$m_{\text{ave}} = \frac{1280 + 960}{4} = 560 \text{ kg}.$$

Averaging the mass of the load leads to an error that does not exceed ±7% relative to the total mass of the elevator hoisting mechanism. For a gearless electric drive with a direct suspension cabin, $i_{\text{tr}} = 1$, is assumed, with a polyspast suspension $i_{\text{tr}} = 2$. In an electric drive with a polyspast, the inertia of the two suspension blocks is additionally taken into account (the inertia of the block is equal to the inertia of the rope-driving pulley), and the inertia of the tension block is not taken into account. Losses mainly depend on the speed of the cabin [16]. Preliminary analysis shows that, for example, for a speed of 2 m/s, the total time of transient processes during upward movement is 43.4 s, or 26% of the total lifting time. For a speed of 4 m/s, movement at a steady speed is practically absent, and the time of transient processes increases to 65 s and is already 44% of the lifting time.

Given the lack of data on the coefficients of excess dimensions of engines λ_{dim}, depending on the adjustment range and duration of switching on, the following values can be recommended: for speeds of 4…6 m/s – $\lambda_{\text{dim}} = 12…15$; for speeds: 1.5…2.8 m/s – $\lambda_{\text{dim}} = 5…10$.

Conclusions

1. In this paper defined are technical recommendations for the selection and systematization of the main operational parameters of passenger elevators in order to further compare the efficiency of their various electromechanical systems.

2. The analysis carried out allows further identifying no more than 40 main variants of popular elevator systems that are subject to technical and economic comparison and differ in design, cabin speed, type of kinematic connection of the cabin with the winch, etc., and as a result, in dynamic parameters (calculated moments of inertia, speeds and accelerations).

3. Analysis of the influence of the elevator lifting mechanism individual inertial elements on the total moment of inertia, reduced to the shaft, shows that in a gearless electric drive, the main inertia is created by the translationally moving parts of the elevator. The same trend is observed in an electric drive with a polyspast cabin suspension.

4. Geared winches are characterized by a greater dependence of the total moment of inertia on the inertia of the drive motor. The inertia of the translationally moving parts of the lifting mechanism of a passenger elevator is only 20…30% of the total moment of inertia, and the "share" of the engine inertia increases significantly. This applies to winches with low-speed engines of the classic design to a greater extent.

5. The influence of the moments of inertia of the elevator engine, the coupling and the brake pulley on the total moment of inertia of the electric drive is insignificant. As a result, for the considered types in the preliminary calculations it is recommended to take a single value of the total moment of inertia regardless of the speed of the lift cabin and the type of electric drive.

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Received May 03, 2025

Accepted June 17, 2025