Lecture Notes in Mechanical Engineering

Vitalii Ivanov · Ivan Pavlenko · Milan Edl · Jose Machado · Jinyang Xu *Editors*

Advances in Design, Simulation and Manufacturing VII

Proceedings of the 7th International Conference on Design, Simulation, Manufacturing: The Innovation Exchange, DSMIE-2024, June 4–7, 2024, Pilsen, Czech Republic - Volume 2: Mechanical and Materials Engineering

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Preface

This volume of Lecture Notes in Mechanical Engineering contains selected papers presented at the 7th International Conference on Design, Simulation, Manufacturing: The Innovation Exchange (DSMIE-2024), held in Pilsen, Czech Republic, on June 4–7, 2024. The conference was organized by the Sumy State University, University of West Bohemia, and International Association for Technological Development and Innovations in partnership with Poznan University of Technology (Poland), Technical University of Kosice (Slovak Republic), Kielce University of Technology (Poland), Association for Promoting Innovative Technologies – Innovative FET (Croatia), and Society for Robotics of Bosnia and Herzegovina (Bosnia and Herzegovina).

DSMIE Conference Series is the international forum for fundamental and applied research and industrial applications in engineering. The conference focuses on research challenges in the fields of Manufacturing Engineering, Materials Engineering, and Mechanical Engineering, addressing current and future trends in design approaches, simulation techniques, and manufacturing technologies, highlighting the growing role of smart manufacturing systems, artificial intelligence, standards-based integration, and innovations implementation to the transition to sustainable, human-centric, and resilient engineering solutions. DSMIE brings together researchers from academic institutions, leading industrial companies, and government laboratories worldwide to promote and popularize the scientific fundamentals of engineering.

DSMIE-2024 received 148 contributions from 33 countries around the world. After a two-stage single-blind review, the Program Committee accepted 83 papers written by 324 authors from 28 countries. Thank you very much to the authors for their contribution. These papers are published in the present book, achieving an acceptance rate of about 56%. Extended versions of selected best papers will be published in scientific journals: Management and Production Engineering Review (Poland), Journal of Engineering Sciences (Ukraine), Advances in Thermal Processes and Energy Transformation (Slovak Republic), Assembly Techniques and Technology (Poland), special issue of Machines (Switzerland) "Innovations in the Design, Simulation, and Manufacturing of Production Systems", and a special issue of Materials (Switzerland) "Novel Approaches in the Design, Simulation, and Manufacturing for Processes and Systems".

We would like to thank members of the Program Committee and invited external reviewers for their efforts and expertise in contributing to reviewing, without which it would be impossible to maintain the high standards of peer-reviewed papers. About 97 Program Committee members and 13 invited external reviewers devoted their time and energy to peer-reviewing manuscripts. Our reviewers come from around the world, representing 21 countries, and are affiliated with 39 institutions.

Thank you very much to the keynote speakers: Prof. Arkadiusz Gola (Lublin University of Technology, Poland), Dr. Foivos Psarommatis (University of Oslo, Norway & ZerOfect Company, Switzerland), Prof. Jinyang Xu (Shanghai Jiao Tong University, China), Prof. Francisco J.G. Silva (Polytechnic of Porto, Portugal), and Prof. Andre Batako (Liverpool John Moores University, UK).

We sincerely appreciate the invited speakers of the DSMIE Workshops: Dr. Bohdan Haidabrus (Riga Technical University, Latvia) and Prof. Katarzyna Antosz (Rzeszow University of Technology, Poland).

The book "Advances in Design, Simulation and Manufacturing VII" was organized in two LNME volumes according to the main conference topics: Volume 1—Manufacturing Engineering and Volume 2—Mechanical and Materials Engineering. Each volume is devoted to research in design, simulation, and manufacturing within the main conference areas.

The second volume consists of four parts. The first part of design engineering aims to increase the service life and reliability of machines' structural components using innovative engineering solutions. Recent advancements in optimization of the counterweight mass of passenger elevators, an increase in the durability of pumping equipment, design improvement of the rotary-pulsation device by resonance phenomena, and modernization of the drive belt transmission for machining centers are also presented in this part. Moreover, it includes experimental justification of the technological parameters for mobile branch trimmers, design improvement and computer modeling of finger grain crushers, investigation of particles' sphericity and roundness, and hysteresis compensation of pneumatic artificial muscles. Finally, an approach for modeling city defense means is also proposed in this part.

The second part includes recent developments in the dynamics and strength of machines, including problems of elastic bending of a strip and the stress-strain state of anisotropic parts, cylinder liners, and tribosurface after preliminary profiling. It also presents the ANFIS system for stress prediction of the cold heading process, methods of calculating the basis reinforced with horizontal elements, and simulation of thermal stresses in multiplayer plates. Moreover, the dynamic analysis of vibration-driven systems and ball launcher systems is discussed in this part.

The third part of process engineering includes studies on vibroextraction by electroimpulse discharges, thermodynamic analysis of coolers, and analysis of cooling air of engines with exhaust recirculation by ejector and absorption refrigeration. Also, it presents studies on modeling turbopump units and evaluating their dynamic characteristics, ensuring the reliability and improving the characteristics of hydraulic drives and hydraulic motors, and enhancing energy parameters of submersible pumps. Moreover, studies on thermophysical processes in thermopressors, improving the performance of centrifugal compressors, and blade thickness optimization are analyzed in the third part.

The fourth part, on advanced materials, is devoted to applying nanomaterials and nanotechnologies to increase agricultural machinery's durability, improve processes of completing a positive connection for hub shafts, and enhance the reliability of paper writing and printing. It demonstrates studies in optimizing surfacing modes for wear-resistant alloys, improving the tribological characteristics of nanometric coatings with increased wear resistance, enhancing anti-friction properties of composite materials, and ensuring the corrosion resistance of cold spraying. The fourth part includes studies on the formation and characterization features of coatings using vacuum-arc deposition and controlling the gas mode of a mold for producing thin-wall castings. Research works on designing nanocomposites for protection against thermal infrared imaging detection systems and simulating waves in polymer materials are also presented in this part.

We appreciate the partnership with Springer Nature, iThenticate, EasyChair, International Innovation Foundation, and our sponsors for their essential support during the preparation of DSMIE-2024.

Thank you very much to the DSMIE Team. Their outstanding involvement and hard work were crucial to the success of the conference.

DSMIE's motto is *"Together we can do more for science, technology, engineering, and education"*.

June 2024

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Design Engineering

Optimization of the Counterweight Mass of a Passenger Elevator

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Abstract. The article develops a universal machine algorithm and program for calculating the energy consumption of a traditional elevator winch with an asynchronous motor and a thyristor voltage converter. It has been determined that the generally accepted expression for calculating the counterweight mass does not consider the parameters of dynamic modes. According to the criterion of minimizing the energy consumed by the electromechanical system, the counterweight has been optimized. Applied to the elevator winches of traditional design with two-speed asynchronous motors with regulation from thyristor control stations, optimization of the counterweight mass, based on the proposed algorithm, can lead to a reduction in its mass by 8–15% (for the elevator mechanism under study by 13.4%). At the same time, the installed winch motor power, energy consumption, and maximum load torque can be reduced by an average of 4–10%. (5.4, 6.2, and 4.4% for the passenger elevator under study, respectively). Using the example of elevator lifting mechanisms with winches of traditional design and parametric control, the recommendations for optimizing the mass of counterweights according to the criterion of minimum energy consumption are given. It is demonstrated that the following indicators can be reduced: the mass of counterweights, energy costs and the installed power of winch motors.

Keywords: Lift Winch · Counterweight Mass · Minimum Criterion · Optimization · Machine Algorithm · Calculation of Energy Consumption · Product Innovation

1 Introduction

Currently, residential and administrative buildings in Ukraine, mainly up to 16 floors, are massively equipped with elevator winches of a traditional design with a worm gearbox, an asynchronous two-speed electric motor (AM), and relay contact control. Many years of experience in their operation have identified many shortcomings that force us to look for ways to increase the level of reliability [1] and improve the dynamic and energy characteristics [2] of traditional elevator winches for mass use [3].

Applying a voltage converter with phase parametric control to power the winch drive motor introduces many features to the overall energy consumption by the elevator lifting mechanism. Simultaneously, detailed calculation and analysis of energy consumption

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allow for selecting the mass of the counterweight not based on an empirical coefficient but based on final information, which will allow to not only assess the degree of influence of the parameters of the lifting mechanism on the total energy losses but also to formulate recommendations for their selection [4, 5].

2 Literature Review

The mathematical model considers the weight of ropes, lift car, and counterweight, suggesting a comprehensive approach to modeling a passenger lift unit in the article [6]. However, the information provided is brief, making it challenging to assess the depth and sophistication of the mathematical model. Introducing a novel procedure based on the Cartesian coordinates suggests an innovative approach to modeling lift systems, potentially offering advantages over traditional methods [7]. Similar to the previous source, the lack of specific details about the procedure and its advantages compared to existing methods makes it difficult to assess the significance of the contribution. The article [8] provides insights into applying modern control technologies in elevator systems. Dynamic equations for start-up, steady motion, and braking are valuable for practical applications in structural design and load capacity setting [9]. Addressing the "drive-transmission-rope-cabin-counterweight" system suggests a holistic approach to analyzing the entire lift system in the article [10]. The weaknesses identified highlight the need for additional information to assess the robustness and significance of the methodologies proposed in each case.

Proposing the direct application of gravity potential energy for energy saving in elevators indicates a focus on sustainable and energy-efficient design. The development of an algorithm to limit counterweight mass and reduce residual vibration suggests a focus on optimizing the mechanical aspects of elevator systems in the work [11]. The focus on energy efficiency control methods without sensors suggests a cost-effective and potentially robust approach [12]. Monitoring the conditions of key mechanical components is essential for preventive maintenance and ensuring the longevity of the elevator system. Additional details on methodologies, validation, and practical applications are necessary for a comprehensive critical analysis.

The reference sources [13] are devoted to analyzing and calculating passenger elevators' dynamic loads due to the presence of elastic mechanical links in rope gears. The topic is relevant in [14] as it addresses a specific aspect (elasticity in rope gears) that can affect elevator performance and safety. Introducing criteria for assessing the effect of elasticity on transient processes suggests a practical approach for evaluating the impact of elastic mechanical links in rope gears [15]. The emphasis on evaluating the elasticity effect without cumbersome calculations aligns with practical considerations for real-world engineering [16].

In summary, while each work addresses essential aspects of elevator system optimization, the limited information in the descriptions makes it challenging to evaluate their contributions thoroughly. Additional details on methodologies, validation, and practical applications are necessary for a comprehensive critical analysis.

This defines the research objectives:

– development of a universal machine algorithm and program for calculating the energy consumed by a winch with an asynchronous motor (AM) (both single-speed and two-speed) and a thyristor voltage converter;
– optimization of the counterweight mass according to the criterion of minimum energy consumption [15].

3 Research Methodology

Despite the relative simplicity of electromechanical transient processes in elevator winches with asynchronous motors, when calculating engine power and electricity consumption, there is a plurality of parameters, the consideration of which is necessary but leads to cumbersome and time-consuming calculations [16]. The synthesis and application of a complex calculation algorithm makes it possible to take into account most of the parameters of the mechanical and electrical components [17], increase the accuracy of calculations, and perform cyclic calculations when varying the values of one or more parameters, which is the basis for finding optimal solutions [18].

To select the counterweight mass of the lifting mechanisms of passenger elevators, a well-known calculation expression is used, considering the balancing of the masses of the cabin and part of the mass of the nominal load:

$$\mathrm{m_c} = \mathrm{m_{abin}} + \varphi\, \mathrm{m_{load}}, \tag{1}$$

where m_{cabin} is the mass of the elevator car, kg; m_{load} – nominal mass of cargo, kg; φ – coefficient of load balancing in the cabin (considering the statistical characteristics of changes in the actual size of the load, it is recommended to take, as a rule, equal to 0.5.)

The idea of optimizing the counterweight mass, according to the criterion of minimum energy consumption, is based on the following basic principles:

– When choosing the power and size of a winch motor with thyristor phase parametric control, the parameters of dynamic modes (dynamic moments, energy losses) are most important for a passenger elevator. Energy consumption in static modes is much less than in transient processes; therefore, the cabin's static balancing principle cannot be considered optimal.
– Passenger flows in residential buildings during ascents and descents differ significantly. Cabin load factors during ascent are more significant than during descent. The average load weight for round trips during peak hours differs from half the rated load capacity. In this regard, the number of starting and braking operations in the most uneconomical propulsion and the braking, more economical modes, when there is a method for selecting the counterweight mass, is not distributed optimally.

The approach to the optimum will be closer if optimization is carried out over as long a period as possible, for example, a year. However, the information necessary for this calculation (average cabin load factors, lengths of trips, and their frequency during ascents and descents) is missing. Therefore, calculations considered the parameters characterizing the elevator operation during peak hours. The initial data required for the calculation are divided into three parts: parameters of the movement of the cabin and passenger flow: speed, acceleration, jerk of the elevator cabin, number of floors of the building, load capacity, load factors of the cabin during ascent and descent, stop time on the floor; parameters of the elevator lifting mechanism: mass of the cabin, mass of the ropes, moments of inertia of the pulleys and progressively moving parts of the lifting mechanism; AM loss coefficients: a_{c2} – loss coefficient in rotor copper; a_{c1} – loss coefficient in stator copper; a_{st} – loss coefficient in steel; a_{mag} – loss coefficient in the stator from magnetizing currents; a_{other} – other losses.

The calculation algorithm involves 5 stages.

Stage 1. At the beginning of the calculation, the preliminary engine power is entered, determined according to the expression [4]:

$$\mathrm{P}_{beg} = (m_{cabin} + m_{load} - m_c)g \cdot V_n. \tag{2}$$

where m_{cabin}, m_{load}, and m_c – masses of the cabin, cargo, and counterweight, respectively; Vн – nominal cabin speed.

The calculation program includes the parameters of the base drive motor: moment of inertia of the motor, rated slip, synchronous speed, rated and maximum torque, efficiency, and rated power losses. At this stage, it is possible to calculate the winch motor power based on the newly adjusted parameters of the lifting mechanism.

Stage 2. The type of optimal elevator movement diagram, based on the specified values of speed, acceleration, car jerk, the number of floors of the building, and the probable number of stops during ascent and descent, is determined at each section of ascent and descent. The optimal diagram for one elementary trip includes starting, running at a steady speed, and braking. This diagram is calculated and divided into 7 characteristic sections, within which the cabin speed changes according to one specific law (Fig. 1): the 1-section is determined by the time t_A of acceleration increases to the nominal value; The 2-section is determined by the time t_B of uniformly accelerated motion at $a = a_i$; The 3rd section is also determined by the time t_A for the acceleration to drop to zero and the transition to steady motion; 4-section is determined by the time t_V of steady motion; Sects. 5, 6, and 7 are characterized by durations similar to Sects. 1, 2, and 3 and describe the deceleration of the elevator car.

Stage 3. Power losses in the winch are calculated using nominal parameters (torque M_n, losses ΔP_n, and slip S_n) and loss distribution coefficients.

Losses in the motor mode when working in the *i-th* section of the optimal diagram are determined as follows:

$$\Delta W_w = \Delta P_n \int_0^t \left[\frac{\mathrm{a}_{c1} + \mathrm{a}_{c2}}{\mathrm{M}_n \cdot s_n} \cdot (\pm M_{ci} \pm M_d) \cdot \left(1 - \frac{\omega(t)}{\omega_0}\right) + \left(a_{mag} + a_{st}\right)\frac{M_i}{M} + a_{other} \right] dt. \tag{3}$$

When working in braking mode

$$\Delta W_b = \Delta P_n \int_0^t \left[\frac{\mathrm{a}_{c2}}{\mathrm{M}_n \cdot S_n} \cdot (\pm M_{ci} \pm M_d) \cdot \left(1 - \frac{\omega(t)}{\omega_0}\right) + a_{stb}\frac{M_i}{M} +_{magb} + a_{other} \right] dt, \tag{4}$$

where $\mathrm{a}_{mag\ b} = \mathrm{a}_{mag}\left(\frac{I_{0b}}{I_{0n}}\right)^2$ is the loss coefficient in the asynchronous motor from the magnetizing current during braking, determined by the ratio of the actual magnetizing current at given values of the torque of the rated no-load current; $a_{st\ b} = 0, 5a_{st}$ – loss coefficient in steel of asynchronous motor during braking.

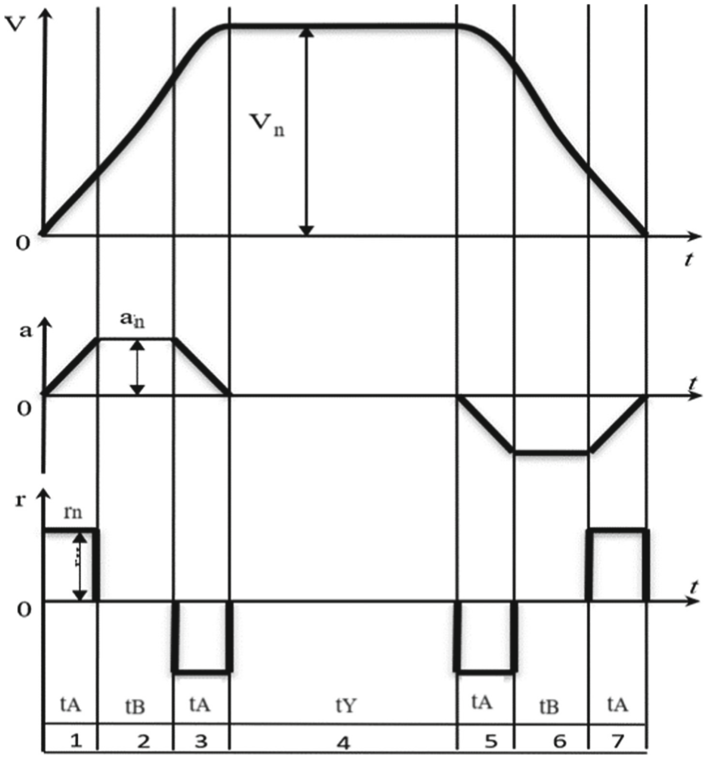

Fig. 1. Optimal elevator car motion diagram.

The winch motor can operate either in driving or braking mode in each of the seven sections of the optimal diagram, depending on the relationship between the magnitudes and signs of the static and dynamic moments. At the same time, each of the sections under consideration is characterized by its own average acceleration value, dynamic torque, and a certain functional dependence of speed on time.

Therefore, after integrating expressions (3) and (4) and substituting the given values of speed, acceleration, and jerk into them, possible loss expressions are determined:

– for motor mode:

$$\begin{cases} \Delta W_1 = \Delta P_n \cdot t_A\left[K_1\left(M_c + \gamma\frac{\varepsilon}{2}\right) - \frac{\varepsilon^2}{6\omega_0 r}\left(M_c + \gamma\frac{3\varepsilon}{4}\right) + \left(a_{st} + a_{mag}\right)\frac{M}{M_n} + a_{other}\right] \\ \Delta W_2 = \Delta P_n \cdot t_B\left[K_2(-M_c + \gamma\varepsilon)\left(1 - \frac{\omega}{2\omega_0}\right) + \left(a_{st} + a_{mag}\right)\frac{M}{M_n} + a_{other}\right] \\ \Delta W_3 = \Delta P_n \cdot t_A\left[\begin{array}{c} K_1\left(M_c + \gamma\frac{\varepsilon}{2}\right) - \frac{1}{\omega_0}\left[M_c\left(\omega_n - \frac{\varepsilon^2}{6r}\right) + \gamma\frac{\varepsilon}{2}\left(\omega_n - \frac{\varepsilon^2}{4r}\right)\right] + \\ +\left(a_{st} + a_{mag}\right)\frac{M}{M_n} + a_{other} \end{array}\right] \\ \Delta W_4 = \Delta P_n \cdot t_Y\left[K_1 M_c\left(1 - \frac{\omega}{\omega_0}\right) - \left(a_{st} + a_{mag}\right)\frac{M}{M_n} + a_{othr}\right] \\ \Delta W_5 = \Delta P_n \cdot t_A\left[\begin{array}{c} K_1\left(M_c + \gamma\frac{\varepsilon}{2}\right) - \frac{1}{\omega_0}\left[M_c\left(\omega_n - \frac{\varepsilon^2}{6r}\right) + \gamma\frac{\varepsilon}{2}\left(\omega_n - \frac{\varepsilon^2}{4r}\right)\right] + \\ +\left(a_{st} + a_{mag}\right)\frac{M}{M_n} + a_{other} \end{array}\right] \\ \Delta W_6 = \Delta P_n \cdot t_B\left[K_1(M_c - \gamma\varepsilon)\left(1 - \frac{\omega}{2\omega_0}\right) + \left(a_{st} + a_{mag}\right)\frac{M}{M_n} + a_{other}\right] \\ \Delta W_7 = \Delta P_n \cdot t_A\left[K_1\left(M_c - \gamma\frac{\varepsilon}{2}\right) - \frac{\varepsilon^2}{6\omega_0 r}\left(M_c - \gamma\frac{\varepsilon}{4}\right) + \left(a_{st} + a_{mag}\right)\frac{M}{M_n} + a_{other}\right] \end{cases}$$

– for braking mode:

$$\begin{cases} \Delta W_1 = \Delta P_n \cdot t_A\left[K_2\left(-M_c + \gamma\frac{\varepsilon}{2}\right) - \frac{\varepsilon^2}{6\omega_0 r}\left(-M_c + \gamma\frac{3\varepsilon}{4}\right) + a_{st}\frac{M}{M_n} + a_{magb} + a_{other}\right] \\ \Delta W_2 = \Delta P_n \cdot t_B\left[K_2(-M_c + \gamma\varepsilon)\left(1 - \frac{\omega}{2\omega_0}\right) + a_{st}\frac{M}{M_n} + a_{magb} + a_{other}\right] \\ \Delta W_3 = \Delta P_n \cdot t_A\left[\begin{array}{c} K_2\left(-M_c + \gamma\frac{\varepsilon}{2}\right) - \frac{1}{\omega_0}\left[-M_c\left(\omega_n - \frac{\varepsilon^2}{6r}\right) + \gamma\frac{\varepsilon}{2}\left(\omega_n - \frac{\varepsilon^2}{4r}\right)\right] + \\ +a_{st}\frac{M}{M_n} + a_{magb} + a_{other} \end{array}\right] \\ \Delta W_4 = \Delta P_n \cdot t_Y\left[K_2(-M_c)\left(1 - \frac{\omega}{\omega_0}\right) + a_{st}\frac{M}{M_n} + a_{magb} + a_{other}\right] \\ \Delta W_5 = \Delta P_n \cdot t_A\left[\begin{array}{c} K_2\left(-M_c - \gamma\frac{\varepsilon}{2}\right) - \frac{1}{\omega_0}\left[-M_c\left(\omega_n - \frac{\varepsilon^2}{6r}\right) - \gamma\frac{\varepsilon}{2}\left(\omega_n - \frac{\varepsilon^2}{4r}\right)\right] + \\ +a_{st}\frac{M}{M_n} + a_{magb} + a_{other} \end{array}\right] \\ \Delta W_6 = \Delta P_n \cdot t_B\left[K_2(-M_c - \gamma\varepsilon)\left(1 - \frac{\omega}{2\omega_0}\right) + +a_{st}\frac{M}{M_n} + a_{magb} + a_{other}\right] \\ \Delta W_7 = \Delta P_n \cdot t_A\left[K_2\left(-M_c - \gamma\frac{\varepsilon}{2}\right) - \frac{\varepsilon^2}{6\omega_0 r}\left(-M_c - \gamma\frac{\varepsilon}{4}\right) + +a_{st}\frac{M}{M_n} + a_{magb} + a_{other}\right] \end{cases}$$

where $K_1 = \frac{a_{c1}+a_{c2}}{M_n \cdot s_n}$; $K_2 = \frac{a_{c2}}{M_n \cdot S_n}$.

Estimated power loss for one round trip of the elevator

$$\Delta P_P = \frac{\sum \Delta W_{w_i} + \sum \Delta W_{U_i} + \sum \Delta W_{b_i}}{\sum \Delta t_{d_i} + \sum \Delta t_{U_i} + \sum \Delta t_{b_i} + \sum \Delta t_0}, \tag{7}$$

where t_0 is the time spent standing on the floor.

Stage 4. Checking the choice of winch motor for heating and overload capacity [6]

$$\frac{\Delta P_n - \Delta P}{\Delta P_n} \leq 0.05, \tag{8}$$

$$M_{max} < M_{max\,d}. \tag{9}$$

Stage 5. Calculating the energy consumed from the network is also carried out, considering the operating mode of the winch, depending on the ratio of static and dynamic moments. When working in motor mode, energy costs consist of energy losses and energy used to perform useful mechanical work on the traction pulley of the lifting mechanism [7]:

$$\Delta W = \int_0^{t_i} M\omega(t)dt. \tag{10}$$

By sections of the optimal tachogram:

$$\Delta W_1 = \frac{1}{\eta}\left(M_c + \gamma\frac{3\varepsilon}{4}\right)\frac{rt_A^3}{6};\ \Delta W_2 = \frac{1}{\eta}t_B(M_c + \gamma\varepsilon)\frac{\omega}{2};$$
$$\Delta W_3 = \frac{1}{\eta}t_A\left[M_c\left(\omega - \frac{\varepsilon^2}{6r}\right) + \gamma\varepsilon\left(\frac{\omega}{2} + \frac{\varepsilon^2}{8r}\right)\right];\ \Delta W_4 = \frac{1}{\eta}M_c t_Y\omega;$$
$$\Delta W_5 = \frac{1}{\eta}t_A\left[M_c\left(\omega - \frac{\varepsilon^2}{6r}\right) - \gamma\varepsilon\left(\frac{\omega}{2} - \frac{\varepsilon^2}{8r}\right)\right];$$
$$\Delta W_6 = \frac{1}{\eta}t_B(M_c - \gamma\varepsilon)\frac{\omega}{2};\ \Delta W_7 = \frac{1}{\eta}\left(M_c - \gamma\frac{3\varepsilon}{4}\right)\frac{rt_A^3}{6}; \tag{11}$$

When the winch motor operates in generator mode, mechanical energy converted into electrical energy is dissipated as heat. Only energy proportional to the losses from the magnetizing current is consumed from the network:

$$\Delta W_b = \Delta P_n t_i \cdot a_{magb}. \tag{12}$$

In the research process based on the developed algorithm, the values of power consumed by the winch and the values of the maximum reduced load moment of the lifting mechanism were also analyzed, in addition to energy costs.

4 Results and Discussion

The results of the study of the basic version of the passenger elevator, the main parameters for which are given in Table 1, showed that with the existing method of static balancing of the cabin weight, taking into account half of the nominal weight of the cargo, all three calculated indicators - winch motor power, energy consumption, and maximum load values are not optimal (Figs. 2, 3 and 4).

For each of these indicators, the value of the optimum counterweight mass turns out to be different, but in all cases, the optimal mass is less than the mass of the actual counterweight of the elevator under study.

Table 1. Basic technical data of the elevator.

Parameter	Units	Values
The nominal speed of the cabin	m/s	1
Load capacity (cargo weight)	Kg	500
Cabin weight	Kg	1250
Counterweight weight	Kg	1500
Height 1-9 floors	M	3.2
Lifting height according to (passport)	M	27.3
Additional movement resistance	N	344
Static tests for 10 minutes	Kg	1150
Dynamic tests with a load	Kg	550
Diameter of the traction pulley	M	0.3
Moment of inertia of the traction pulley	kg•m^2	4.6
Type of gearbox	RGL=180-47	
Type of drive motor	ACC 92-6/24	
Type of control station	TCUR-2	
Diameter of traction ropes	mm	
Number of ropes of traction ropes	mm	
The specific gravity of the traction rope	kg/m	
Length of the traction rope	m	
Mass of traction ropes	Kg	
Moment of inertia of brake pulley	kg•m^2	
Electromagnetic brake torque	N•m	

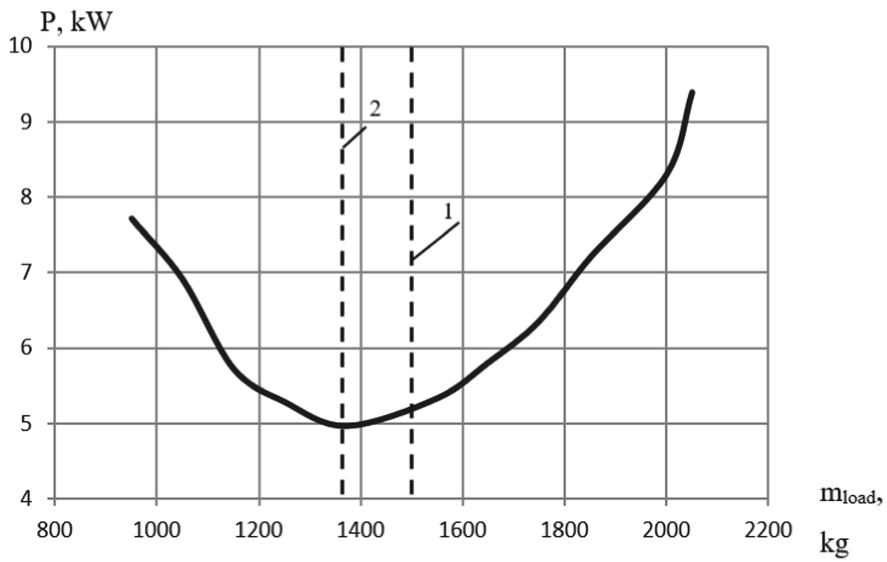

Fig. 2. Dependence of power consumption on counterweight mass: 1 – before optimization, 2 – after optimization.

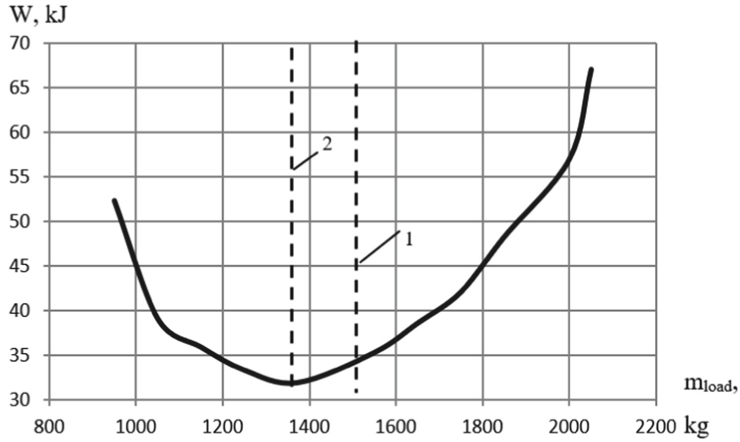

Fig. 3. Dependence of the energy consumed during one round trip on the counterweight's mass: 1 – before optimization, 2 – after optimization.

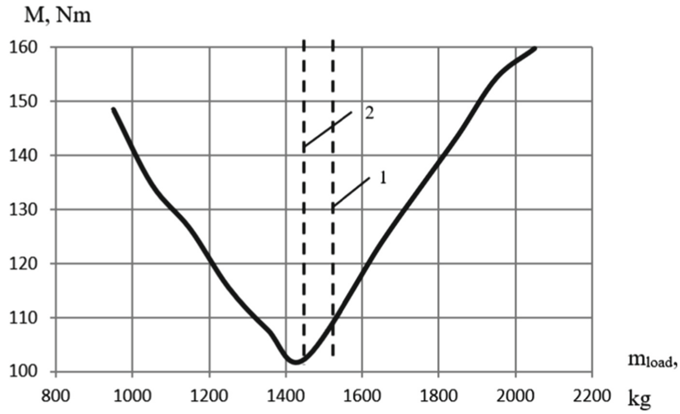

Fig. 4. Dependence of load moment on counterweight mass: 1 – before optimization, 2 – after optimization.

5 Conclusions

Applied to the elevator winches of traditional design with two-speed asynchronous motors with regulation from thyristor control stations, optimization of the counterweight mass, based on the proposed algorithm, can lead to a reduction in its mass by 8–15% (for the elevator mechanism under study by 13.4%). At the same time, the installed winch motor power, energy consumption, and maximum load torque can be reduced by an average of 4–10%. (5.4, 6.2, and 4.4% for the passenger elevator under study, respectively).

It has been determined that the generally accepted expression for calculating the counterweight mass does not take into account the parameters of dynamic modes; difference in passenger flows during ascents and descents; difference in cabin load factors during ascent and descent; the difference between the average value of the amount of cargo moved during round trips during peak hours and half of the rated load capacity.

It is shown that the number of starting and braking operations taking place in the propulsion, the most uneconomical, and in the braking, more economical, modes is not distributed optimally with the existing method of choosing the counterweight mass.

A method for calculating the optimal counterweight mass to minimize the energy consumed by elevator winches is proposed. A universal software algorithm has been developed that allows a comprehensive implementation of the proposed method.

Using the example of elevator lifting mechanisms with winches of traditional design and parametric control, the recommendations for optimizing the mass of counterweights are given according to the criterion of minimum energy consumption. It is demonstrated that the following indicators can be reduced: the mass of counterweights, energy costs, and the installed power of winch motors.

The obtained patterns for the formation of control actions in order to obtain standardized modes of a passenger elevator are universal for all elevator winches of "traditional design" with a worm gearbox, a two-speed asynchronous motor, and a thyristor control system.

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