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Assessment of load of load-bearing elements of the passenger elevator based on regular monitoring results

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Introduction: This article is devoted to improving the safety of elevators — the most popular hoisting-and-transport devices. The paper presents the results of an indirect assessment of load of load-bearing elements of elevators for residential buildings based on the results of regular monitoring by service organizations.

Problem Statement. Processing of the monitoring results was carried out on the basis of the idea of random nature of influencing factors and performance indicators. The data of observations of 15 elevator units of various load capacities installed in residential buildings with different number of storeys and passengers were processed.

Theoretical Part. The following indicators are accepted as the main ones, which characterize the load of the main elevator drive: machine time coefficient and specific number of starts per minute of pure machine time. For each of the indicators, distribution functions and probability densities are constructed.

Conclusion. Indicators of loading of the elevators vary within wide limits; no stable correlation between the indicators was established; each elevator is characterized by a pair of values of the machine time coefficient and the number of inclusions. The main purpose of the results is the possibility of using them to assess the adequacy of the formation of loading modes in the simulation of passenger elevators in comparison with real indicators.

Keywords:safety of elevators, monitoring the operation of elevators, actuator loading factors, ratio of computer time, switching frequency of the main drive, statistical characteristics of the operation modes of the elevator.

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Introduction. The elevator is one of the most popular and widely used lifting and transport devices [1]. The current technical regulations of the Customs Union define it as: "an elevator is a device designed to move people and (or) cargo from one level to another in a cab moving along rigid rails that have an angle of inclination to the vertical of no more than 15° [2].In this article, the term "elevator" is used in accordance with this definition.

In the Russian Federation, according to the National Elevator Union (NLS) and the National Association of Liability Insurers (NSSO), about 550 thousand elevators are operated, which are subject to the Federal service of Rostechnadzor in terms of ensuring safe operation. The number of elevators is increasing rapidly in line with the growth of multi-storey housing construction in the country.

Elevators are classified as high-risk equipment. According to the combined data of the NLS and NSSO, over the past three years, about 100 accidents occurred during the operation of elevators, in which 40 people were killed and about 100 people were injured.

Ensuring safe operation of elevators is a complex multi-faceted task, the complex solution of which is formulated in the current regulatory documents. Among the most important topical directions of solving this problem, the authors highlight the need for a well-founded methodological approach to planning and implementing maintenance programs for each elevator unit, taking into account the actual accumulated number of cycles and the equivalent level of loading [3-4]. This approach will ensure:

— guaranteed level of safety during the entire period of operation;

— possible stabilization of maintenance costs.

For reasonable planning of maintenance programs and repair impacts during the operation of elevator units, actual information about the operating modes of power elements, especially the main drive, is required — the duration of the switched-on state in each cycle of operation, the specific number of starts, brakes, etc. As it is known, elevators operate under the conditions of regular influence of random factors — the frequency of requests for their use, the value of the end load, the duration of the switched-on state, the frequency of starts, and many others [5-6]. Systematization and generalization of these impacts will create scientifically based requirements for the development of maintenance algorithms.

To create such a database, it is advisable at the first stage to use the materials of regular observations of the actual operating modes of elevators with objective recording of the results carried out by specialized service organizations. In the future, it is possible to create the necessary scientific and methodological base by developing procedures that are adequate to real processes for simulating the operating modes of elevator units and establishing the relationship between operating modes and operating loads [7]. This article uses the materials of regular monitoring and computer database of LLC Liftservis, Rostov-on-Don.

Taking into account the above mentioned information, the purpose of this work is to obtain regular observations of the laws of formation of loading modes for power elements of passenger elevators on the basis of statistical processing of data.

1. Methods of research and statistical processing of data from regular observations. The main stages of the study were as follows:

— selection of observation objects taking into account the influence of parameters and operating conditions of elevator units;

— substantiation of the main characteristics of the operation and loading modes of the elevator units (statistical distributions and average values);

— development of methods for processing raw data.

Residential buildings equipped with elevator units were selected as objects of observation. The main influencing factors are the floor of the house, the number of entrances and elevator units, and the availability of goods elevators. As a result of the analysis, six houses (6, 16, 21, and 24 floors) with one, two, and three entrances were selected with different levels of population density (Fig. 1). Quantitative parameters are given in table 1.

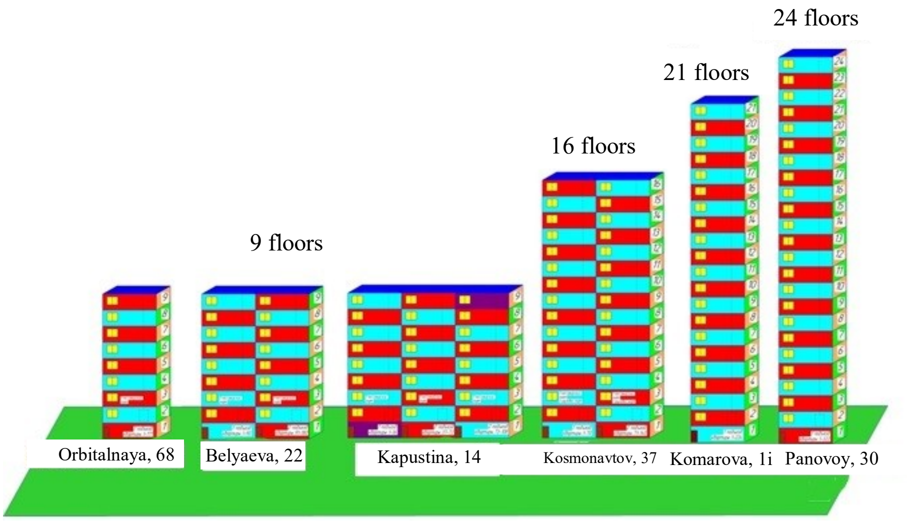


Fig. 1. Objects accepted for monitoring

Table 1

Quantitative characteristics of observational objects

Adress of the building	Number of floors	Number of entrances	Entrance	Type of the elevator (number on the pictures)	Loadcapacity, kg	Estimated number of residents served by the elevator
Orbitalnaya, 68	9	1	No. 1	Passenger (1)	400	513
Belyaeva, 22	9	2	No. 1	Passenger (2)	400	270
			No. 2	Passenger (3)	400	270
Kapustina, 14	9	4	No. 1	Passenger (4)	400	108
			No.3	Passenger (5)	400	108
			No.4	Passenger (6)	400	108
Kosmonavtov, 37	16	2	No.1	PassengerNo. 1 (7)	400	105
				GoodsNo. 1 (8)	630	105
Komarova, 1i	21	1	No. 1	PassengerNo. 1 (9)	400	168
				PassengerNo. 2 (10)	400	168
				GoodsNo. 1 (11)	630	168
				GoodsNo. 2 (12)	630	168
Panovoy, 30	24	1	No.1	PassengerNo. 1 (13)	630	322
				PassengerNo. 2 (14)	630	322
				Passenger № 3 (15)	630	322

The following monitoring results were taken as the initial characteristics of the operating and loading modes of the elevator unit, primarily the main drive (MD): the net time of on-state (t_{M}, s) and the number of starts (N_o) during each calendar hour. For each observed elevator, the initial indicators are obtained in the form of diagrams (fig. 2,3,4 and 5) or tables. The observation period was 10800 minutes (7,5 days, 180 hours).

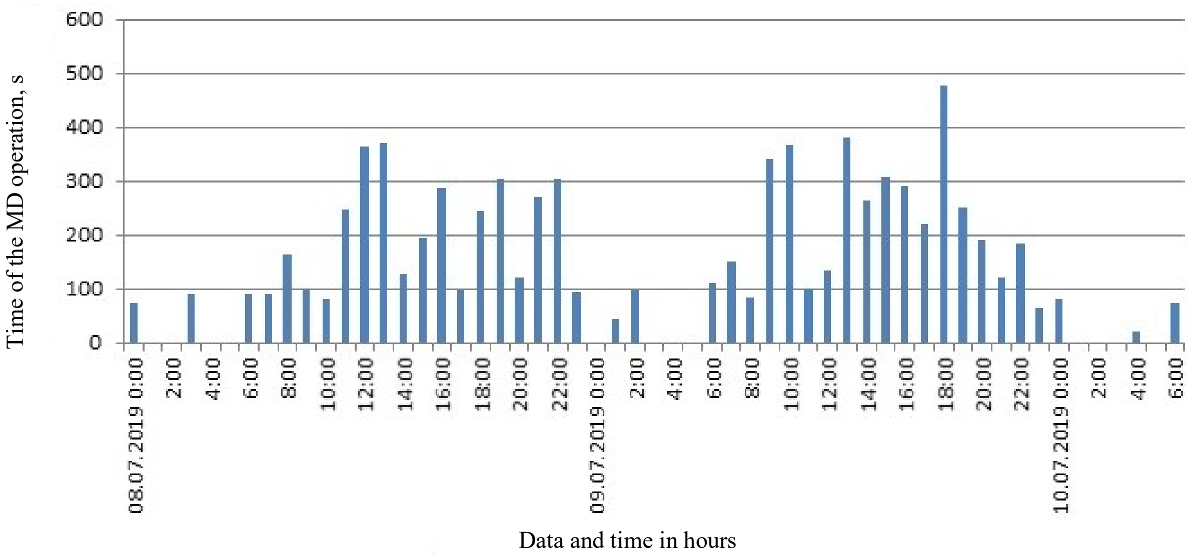


Fig. 2. Net operating time of the MD per hour (14 Kapustinastreet, entrance 3)

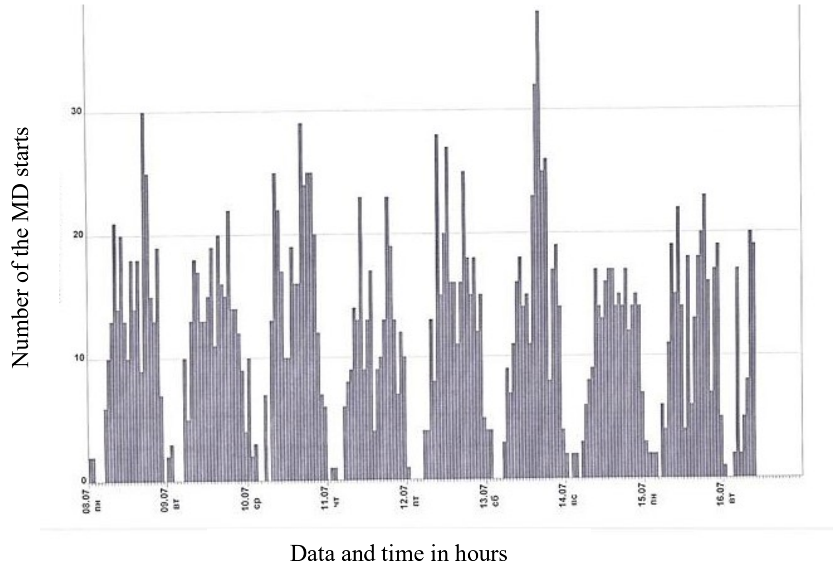


Fig.3. Number of GP starts per hour (14 Kapustinastreet, entrance 3)

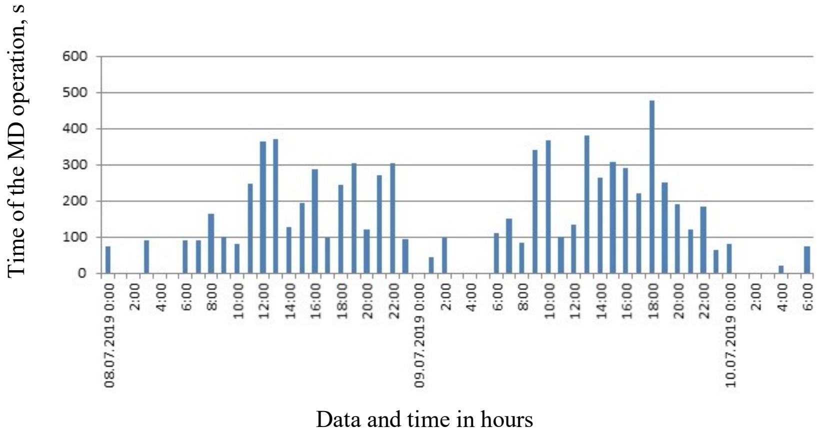


Fig. 4. Net operating time of the MD per hour (68 Orbitalnayastreet, entrance 1)

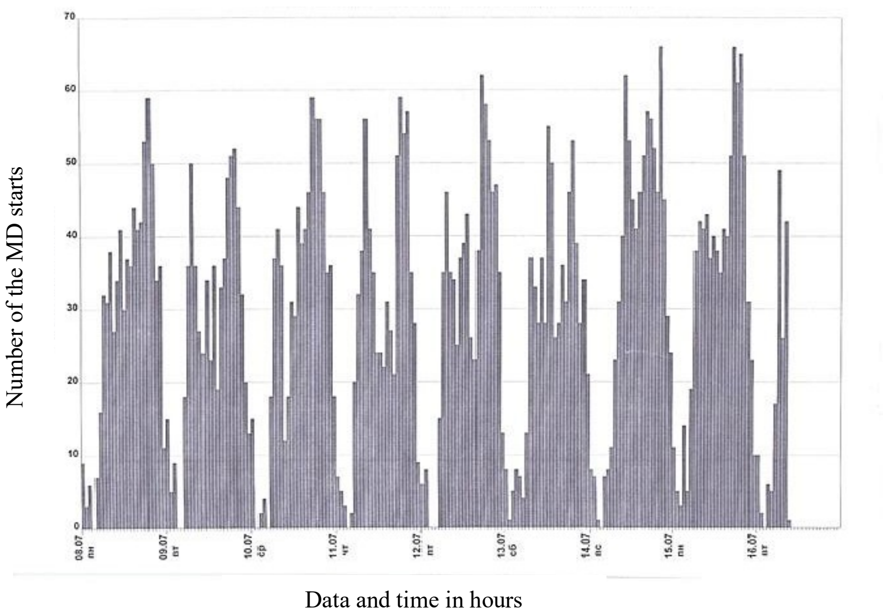


Fig. 5. Number of GP starts per hour (68 Orbitalnayastreet, entrance 1)

Figures 3 and 5 show samples of the source data used for subsequent statistical processing.
Program statistical processing was to obtain such characteristics: the duration of the elevator operation and

switching of the main drive, which, on the one hand, would serve as a basis for comparison of the loading actuator and other components of various elevator units, for the formation of generalized characteristics necessary to evaluate the adequacy of the experimental data and the results of plan simulation [8].

Based on these tasks, the indicators of the load mode of the elevator MD are:

— machine time coefficient K_m, as the ratio of the net to the total operating time of the elevator (and the MD) for the entire observation period;

— the specific number of the MD starts in the net machine time (starts per minute).

Each of these indicators characterizes different aspects of the operation mode of the elevator unit. The machine time coefficient K_m evaluates the relative duration of the engine's switched-on state, its thermal mode in comparison with the permissible one for this engine. The number of starts *n* determines the conditional level of dynamic loads during starts and decelerations.

Each of the selected indicators is a random variable, for the evaluation of which it is necessary to consider a set of numerical and functional characteristics [9]. Average values and average square deviations are used as numerical characteristics. Functional characteristics are represented by distribution functions F(x) and probability density f(x), where any of the considered indicators is taken.

The data processing procedure is as follows:

1. Processing is carried out for each elevator separately.

2. Creation of a complete unified set of data for each elevator for the entire period of multi-day observations, for each day — for 24 hours.

3. Every day table 2 is filled in: the coefficient of machine time k_m and the specific number of starts of the main drive of the elevator per minute of net machine time n.

4. The entire range of $k_м$ and n from the minimum to the maximum is divided into 10 equal parts; the ranges (digits) are numbered from 1 to 10. The ranges are set **uniform** for all elevators –Δk_m and Δn. This condition must be met to compare the operating modes and load levels of elevators.

5. The total number of $K_{m\Sigma}$ and N_Σ values and the number of values k_{Mi} and n_i, that fall within this range are calculated (I is the number of the range).

6. The frequency of values falling into this range is calculated:

$$p_{ki}= k_{Mi}/ K_{m\Sigma} и p_{ni}= n_i/N.$$

The sum of all the frequencies for each elevator must be equal to 1

Table 2

Primary processing of daily data for passenger elevator No. 1

(address: Kapustina street, 14: floors – 9, number of entrances – 2, total elevators – 4, including passenger elevators – 4, 2 in each entrance, the number of apartments – 36; the estimated number of residents served by this elevator – 108, maximum load capacity – 400 kg; observation period – from 07.07.2019 (from 22.00) to 08.07.2019 (to 22.00), i.e. only 24 hours, or 1440 minutes, or 86 400 seconds.)

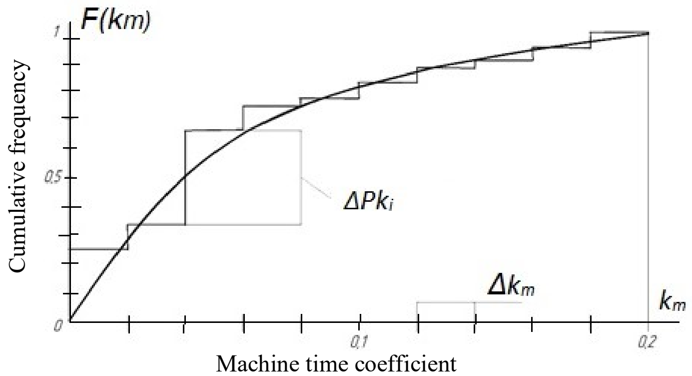
Characteristics of the elevator operating mode during 24 hours of daily operation				
Currenttime, hour.	Duration of the elevator's net machine operating time per hour, t_m, c	Coefficient of machine time of elevator operation during a given hour, $k_m= t_m$ /3600	The number of starts is the main drive for this hour, $N_ч$	Specific number of starts during an hour of net machine time $n=N_ч/k_m$,1/час
Date: 07.07.2019				
Night mode				
22	208	0,057	14	246
23	143	0,040	8	200
Date: 08.07.2019				
00	103	0,029	6	207
01	0	0	0	0
02	39	0,011	4	364
03	0	0	0	0
04	0	0	0	0
05	0	0	0	0
06	46	0,013	8	615

Characteristics of the elevator operating mode during 24 hours of daily operation				
Currenttime, hour.	Duration of the elevator's net machine operating time per hour, t_m, c	Coefficient of machine time of elevator operation during a given hour, $k_m = t_m/3600$	The number of starts is the main drive for this hour, $N_ч$	Specific number of starts during an hour of net machine time $n=N_ч/k_m$,1/час
Morning mode				
07	211	0,059	11	188
08	162	0,045	12	267
09	238	0,066	16	242
10	574	0,159	30	188
Day mode				
11	204	0,057	14	247
12	214	0,059	12	202
13	165	0,054	9	196
14	244	0,068	16	236
15	292	0,081	15	185
16	190	0,053	12	227
Evening mode				
17	267	0,074	14	189
18	217	0,060	16	265
19	423	0,112	24	204
20	432	0,12	31	258
21	438	0,122	29	238
Total: 24 hours of total time	4810 s. of net machine time during the day	0,0557 – average$k_m$per day	301 starts in 24 h., or 12.54 starts in an hour of total working time	n=3,75 starts./minute – average value n

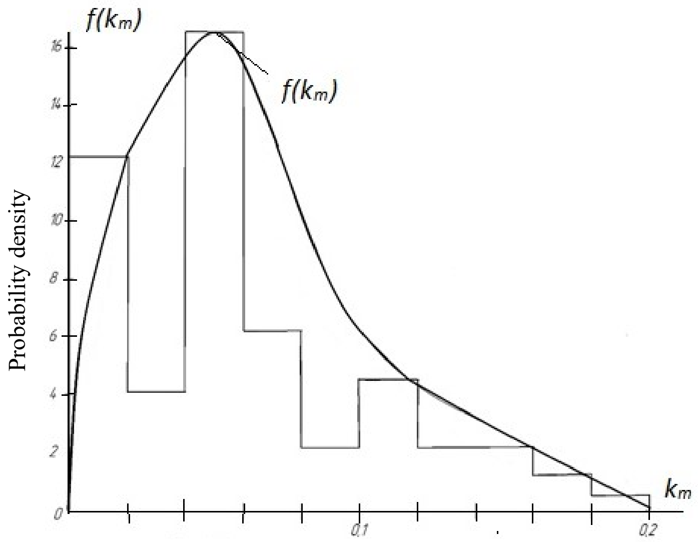
7. Based on item 6, a graph of accumulated frequencies for each elevator is constructed. These graphs are essentially experimental distribution functions for random variables k_m, N– $F_1(k_m)$ and $F_2(n)$ (fig. 6,a).

8. We calculate the density distribution values of K_m and N for each elevator —$f_1(k_m)$ and $f_2(n)$. To do this, in each range, the frequency increment (item 6) is divided by the range (item 4) —$f_{1i}(k_{mi})=\Delta p_{ki}/\Delta k_m$ and $f_{2i}(n_i)=\Delta p_{ni}/\Delta n$. The resulting value is put on the distribution density graph in the middle of the range (Fig. 6, b). For example, figures 6,a and 6,b show the calculation of the distribution density of the value K_m on the K_m=(0,04;0,06). The probability of a random variable K_m hitting this section is equal to the difference in the values of the distribution function (frequency) Δp_k=0,663-0,333=0,33 (fig.6,a). The probability density is equal to the ratio of Δp_k to the K_m change in the section ΔK_m=0,02, i.e. $f(k_m)$=0,33/0,02=16,5 (fig.6,б). Checking the correctness of constructing the functions $f_1(k_m)$ and $f_2(n)$ consists in estimating the area under the distribution density curve, which should be close to one.

2. The set of regular initial data for the group of elevator units. The selected set of observation objects — elevator units — can be characterized as sufficient, which is characterized by a combination of various factors that significantly affect the operating modes and equivalent loads (table 1 and fig. 1). Among the units accepted for monitoring are houses of various storeys (9 ... 24 floors), elevators of various load capacities and purposes (400...1000 kg). The estimated number of residents served by the elevator is also different. The observation period can also be considered sufficient, with all objects surveyed for one fixed period of time (more than 7 days of continuous monitoring).



a)



b)

Fig. 6. Construction of the distribution function $F(k_m)$ (a) and the probability density $f(k_m)$ (b) on the example of the machine time coefficient K_m

This allowed us to obtain a representative sample of random elevator performance indicators, the main purpose of which is to serve as a basis for comparing real indicators with the results of simulation.

The data obtained from regular monitoring of the operating modes of elevator units can be considered a representative sample both in terms of volume and the number of factors considered. For each of the elevators, the volume of continuous observations is more than 180 hours with a record of the net operating time and the number of starts during each hour.

The necessary number of observations was estimated using the student's distribution [10]. To determine the required number of observations, the following ratio is valid:

$$N_{\text{набл}} \geq \left[\frac{K_\sigma f(\beta)}{\text{О}_\text{ш}}\right]^2,$$

whereK_σ – the coefficient of variation of experimental data, i.e. the ratio of the average square deviation to the average value of a random variable;

$f(\beta)$ – a parameter in the Student's distribution that depends on the accepted confidence level β;

$\text{О}_\text{ш}$ – an acceptable error in determining the average value of a random variable (by the level of responsibility of the process).

The calculated data for the data on the average values of the elevator machine operating time coefficient and the number of main drive starts based on the results of regular monitoring are shown in table 3.

Table 3

Estimation of the required number of daily observations

Indicator of the elevator operating mode	Averageval ue	Meansquare deviation	Coefficient of variation, K_σ	Confidence probability, β	Parameter in the Stu-dent's dis-tribution	Acceptable error in determining the average value	Required number of observations per day
Specific number of MD starts, 1/min.	3,75	1,16	0,31	0,9	1,66	0,1	26
	3,75	1,16	0,31	0,9	1,66	0,12	19
Coefficiento fmachinetim e	0,15	0,05	0,33	0,9	1,66	0,1	29
	0,15	0,05	0,33	0,9	1,66	0,12	21

The estimates of the required number of daily observations to obtain a sample with an error of no more than 12% at a confidence level of 0.9 indicate that measurements of regime indicators once per hour (24 measurements per day) can be considered sufficient.

The main results of processing the primary monitoring data for each elevator unit were the average values of the machine time coefficient k_{mcp} and the number of MD starts per minute of net machine time N_{cp}, as well as the functional characteristics of these random variables — the distribution functions $F(k_m)$, F(n) and the probability density $f(k_m)$, f(n). The main results are presented in a compact form in table 4 and in figures 7 and 8.

Table 4

Average values of the modes of operation of the elevators

Elevator numbers according to table 1	1	2	3	4	5	6	7
Machinetimecoeffi cient	0,190	0,089	0,149	0,056	0,063	0,040	0,145
Number of starts, 1/min	2,45	2,13	1,90	3,43	2,75	2,86	1,95
Elevator numbers according to table 1	8	9	10	11	12	13	14
Machinetimecoef-ficient	0,065	0,088	0,107	0,080	0,122	0,090	0,166
Numberofstarts, 1/min	1,83	3,08	2,25	1,89	1,90	1,47	1,87

For elevator15: k_{mcp}=0,186; N_{cp}=2,0

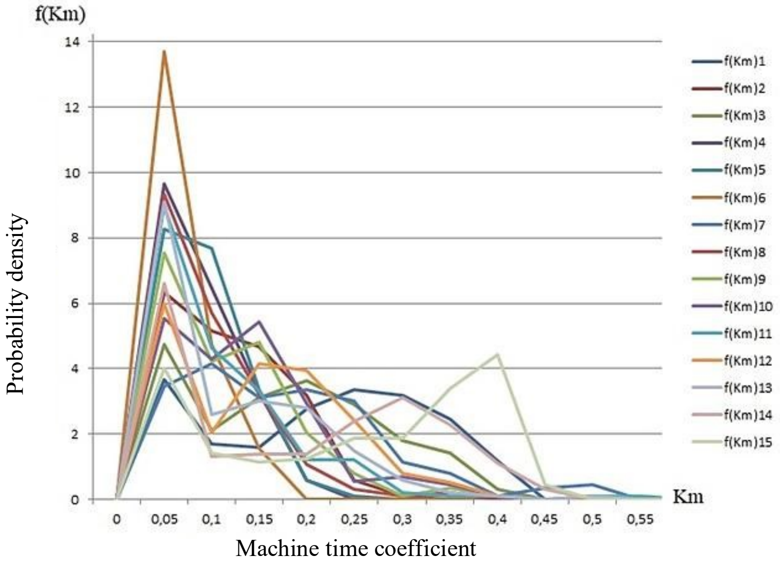


Fig. 7. Probability density of the machine time coefficient

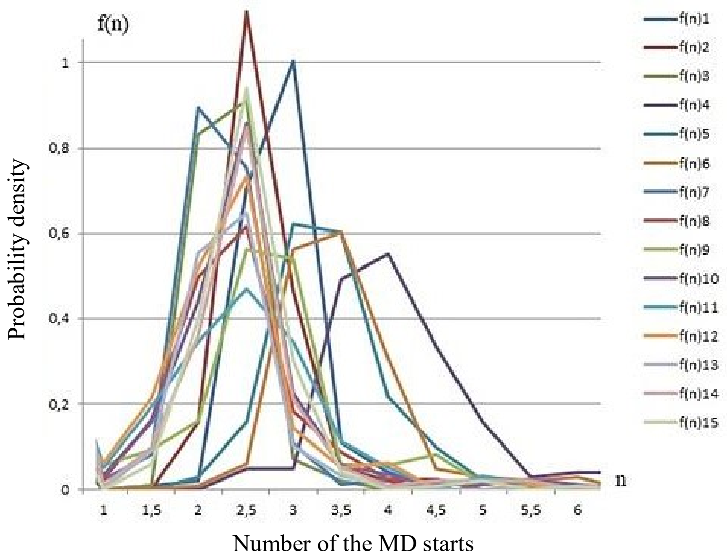


Fig. 8. Probability density of the specific number of starts

3.Assessment of the influence of the most important factors on the calculated load of power elements of elevator units. The analysis of monitoring data and their processing show:

— the main indicators of the operating mode of the elevator MD vary widely: the coefficient of machine time — five times, from 0,04 to 0,19, the number of inclusions per minute of net machine time — 1,87 times, from 1,83 to 3,43;

— the machine time coefficient objectively characterizes the net time when all elevator elements are in working condition, the values of this coefficient for most units are at a low level (0,05...0,12), this indicates a significant underloading of the main drive and other components;

— the specific number of starts determines the frequency of application of dynamic loads on the drive, ropes, cab structure and other components, the characteristic value of the number of starts from 2 to 3 per minute of net machine time, in terms of the hourly frequency of starts, this will be 120 ... 180 starts, which is quite acceptable for the engines used;

— a stable correlation between k_m and n indicators was not found, although the trend of increasing the machine time coefficient with a decrease in the specific number of starts can be traced, 9 lifts out of 15 taken for monitoring fit into this relationship:

n	1,45	1,90	1,90	1,95	2,25	2,75	2,17	2,86	3,43
k_m	1,95	0,149	0,122	0,0,146	0,107	0,063	0,089	0,04	0,056

— each lift is characterized, usually individual a pair of values of k_m and n, the value of which depends on a number of factors: the number of storeys of the building, number of residents for the elevator, elevator load-carrying capacity, the average time between two adjacent requests to use the elevator and some other;

— with the increase in the number of storeys of the building, the coefficient of machine time increases, while, as a rule, the specific number of starts does not increase, this is due to the fact that the average length of the elevator movement during the cycle of use increases, and the number of intermediate stops remains at the same level;

— the main influence on the load indicators of the elevator is the number of residents who actually use the elevator, as shown by the analysis, the real number of users may differ significantly from the estimated number of registered persons in a given entrance or building; for example, when comparing the indicators of two elevators with different estimated number of residents (table. 4) we have:

— Elevator no. 1 (68 Orbitalnaya street): floors — 9, residents — 513, k_m/n=0,19/2,45;

— Elevator no. 15 (30 Panova street): floors — 24, residents — 630; k_m/n=0,186/2,0.

Conclusion. The performed research allowed us to obtain regular observations of the main regularities of the formation of loading modes of passenger elevators power elements on the basis of statistical processing of data.
A significant influence of random factors that form the main indicators of elevator loading — the coefficient of machine time and the specific number of starts.

The main purpose of the obtained results is to be able to use them to assess the adequacy of the formation of loading modes in the simulation of passenger elevators in comparison with real indicators.

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Contribution of the authors

G.Sh. Khazanovich – development of research methods and statistical processing of the initial data, final analysis of the results of the study, conclusion. D.S. Apryshkin – processing of the original data observations, construction of the main dependencies, graphic design, evaluation of the influence of the most important factors on the calculated load of the load-bearing elements of elevator installations.