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# Methods for Analysis and Improvement of Dynamic Loads on the Steel Wire Rope Holding the Boom of Steel Wire Rope Excavators

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**ABSTRACT**
The article analyzes the dynamic loads on the booms of single-bucket quarry excavators and steel cables between two supports and develops design solutions to reduce them. The boom of quarry excavators and steel cables between two supports are located separately on both sides, and as a result of stretching the steel cables, the tension force on the steel cable on one side of the boom increases, which not only has a dynamic effect on the steel cable of this side, but also leads to curvature of the boom. The methods used in the article are analyzed based on the equilibrium equations of the distribution of static and dynamic loads and the finite element method. Based on the programs, a new model of the structural arrangement of the boom and two supports is created and an analysis of the results obtained from the calculations is obtained. As a result of creating a new design model by installing steel cables supporting the excavator boom on two supports as a half-block, uniform distribution of steel cable tension and maintaining automatic tension balance are achieved, which reduces dynamic loads and extends the service life of working mechanisms, and also reduces the risk of accidents by monitoring the dynamic loads of steel cables in real time, which leads to a significant contribution to ensuring the safety of workers. The practical significance of the article is that installing half-blocks on two supports serves to increase the operational reliability of excavators and prevents operating costs and the appearance of cracks in the boom by increasing the efficiency of maintenance, preventing ruptures and defects resulting from improper tension of steel cables, due to ensuring the balance of loads on steel cables, excessive loads on the working mechanisms are eliminated, which leads to an increase in the service life of the steel cable by 15-20%.

***Keywords:*** excavator, steel wire ropes, loading, dynamic balance, static balance, design solution, operation, maintenance, section.

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## Introduction

Steel wire ropes of excavators that are used in mining environment play an important role in the working process of the excavator. These steel wire ropes enter the suspension system of the excavator and participate in controlling its arm and bucket movements [1].

Research is being conducted around the world to improve the reliability of excavator working members. Steel wire ropes have been analyzed from a mechanical point of view to improve the load-bearing efficiency and reliability of excavators [2]. Also, methods of dynamic analysis of excavator mechanisms with steel wire ropes based on a virtual prototype were proposed [3], which allows optimizing the loads on steel wire ropes. A dynamic analysis of the excavator boom section of steel wire ropes was carried out using the FEA (finite element analysis) method [4]. These studies are aimed at theoretically and experimentally studying the loading process of excavator steel wire ropes, which provides a basis for studying advanced approaches in this area. In Western Europe and the USA, mainly intelligent monitoring systems are being introduced to solve problems related to excavator steel wire ropes. Steel wire ropes recommended the use of new composite materials to increase the load-bearing capacity of the excavator boom and its main parts. This approach allowed increasing the durability of the cables by 10-15% [5].

In Russia and China, the main focus is on automating the load distribution of steel wire rope excavators, where algorithms have been developed to optimize the loading of the trusses and reduce moment imbalance. According to the results of this study, it was found that the load difference can be reduced by 5-10% [[6], [7]].

Steel wire ropes and their main function - Steel wire ropes are one of the main elements of the lifting and balancing system that moves the working members of the excavator. Their main functions are to ensure the lifting and lowering of the bucket, ensure the stability of the excavator boom, and ensure the forward and backward movement of the bucket.

The scientific novelty of the research presented in this article and the difference from the results of previous works is that a new design solution and an automatic balancing model have been created to reduce the dynamic loads of steel cables of the excavator rack, the effectiveness of which has been proven by modeling and precise calculations.

The essence of scientific novelty is as follows:

By proposing an automatic dynamic force equalization mechanism, the problem of uneven distribution of forces between several parallel steel cables in the boom section of the excavator was analyzed for the first time in the scientific work, and an automatic equalization mechanism was created. This mechanism allows for the synchronization and balancing of the dynamic loads applied to the steel cables during movement.

Analysis of the dynamics of forces in real time was carried out by means of mechanical modeling, i.e., the change in dynamic forces acting on steel cables as a function of time. This provides accuracy not only in calculating static, but also dynamic loads (Table 1).

**Table 1** - The difference from previous scientific research

| Direction | Previous research | In this article |
|---|---|---|
| Dynamic load analysis | Static or general theoretical analyses | Complete dynamic analysis (graphs, time functions) |
| Constructive solutions | Mainly material substitution or algorithms | New structural system - automatic power balance |
| Modeling method | Classical methods or general FEA | Complete mechanical modeling based on COMPAS-3D |
| Scientific results | Partial effect, load reduction up to 5-10% | Efficiency at load balance 20-50%, service life increase 30-40% |

This research is distinguished as a scientific and practical innovation in the modernization of steel cable boom systems, which are of great importance for quarry excavators. It covers the stages of not only identifying the existing problem, but also proposing, calculating, and proving a specific technical solution for its solution. This work demonstrates a new level of analytical, technical, and engineering approach to previous research.

Types of steel wire ropes Steel wire ropes used in excavators of the EKG-8I, EKG-10 and EKG-15 types are divided into:

- bucket lifting steel wire ropes - used to raise and lower the bucket;
- boom holding steel wire ropes - hold the boom in the desired position;
- traction steel wire ropes - participate in moving the bucket forward;
- balancing steel wire ropes - help to keep the excavator in a stable position.

The material and properties of steel wire ropes of the 52.0 G-V-O-N-160 brand are as follows [[8], [9]]:

- bucket lifting steel wire ropes - made of special alloys that can withstand high tension;
- tensile strength - since the excavator is subjected to repeated bending and stretching during operation, the cables must be resistant to bending;
- corrosion-resistant coating - special coatings are used to resist moisture and dust in quarry conditions.

Steel wire ropes are mainly used in excavators, with φ 39 mm diameter steel wire ropes in EKG-5A excavators, φ45.5 mm diameter steel wire ropes in EKG-8I excavators, φ52 mm diameter steel wire ropes in EKG-10 excavators, and φ57 mm diameter steel wire ropes in EKG-15 excavators. These steel wire ropes are manufactured in accordance with GOST 2688-80 standards, depending on the manufacturer [[10], [11]].

## The experimental part

Currently, the steel wire ropes of excavators of the EKG-8I, EKG-10 and EKG-15 types are constructed based on the design shown in Figure 1 below, in which case the excavator boom is subjected to a large load due to the imbalance of the tension forces in the steel wire ropes holding it[[12], [13]]. When installing steel wire ropes on the boom, the incorrect distribution of the load on the rope leads to a decrease in the service life of the excavator boom, defects and breakage of the steel wire ropes. The boom of excavators of the EKG-8I, EKG-10 and EKG-15 types consists of a head block 1, 2- steel wire ropes 2, a saddle bearing 4 is located between the upper 3 and lower 6 sections of the boom for installing a single-beam lever, and the boom is held by a two-legged column 7 and a holder 5 [[14], [15]].


**Figure 1 -** View of the excavator boom and steel wire rope

1- head block; 2- cable; 3- boom upper section; 4- saddle bearing; 5- retainer; 6- boom lower section; 7- two-legged column [14].

If the steel wire ropes of an excavator are not of the same length or tension, the boom will be unevenly positioned under dynamic and static loads. This will result in the following forces [21]:

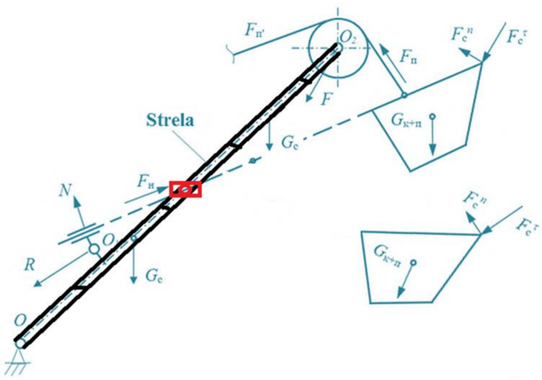


**Figure 2 -** Scheme for determining lifting and compressive forces

The main forces acting on the boom Fig. 2 shows the movement of the excavator boom under static and dynamic loads. Based on this diagram, the following forces act:

- $G_c$ - arrow weight, directed downwards, *t*.
- $G_{k+m}$ - weight of the load-bearing block and steel cable, *t*.
- $F$ - tensile force applied by the steel cable, N.
- $F_H$ - horizontal reaction force (support reaction), *N*.
- $N$ - normal reaction force, *N*.
- $R$ - total reaction force). ($R = \sqrt{N^2 + F_H^2}$)

- $F_n, F_{n'}$ - projections in the direction of the forces, *N*.
- $F_c, F_{c'}$ - centripetal forces, *N*.

Equilibrium equations of the resulting forces Equilibrium equations are formulated based on Newton's second law for the equilibrium of an arrow in a stationary state:

Equilibrium equations for the projections of load forces:

Horizontal (OX) direction:

$$\sum F_x = 0 \rightarrow F_H + F_{n'} - F_c \cdot \cos\theta = 0 \qquad (1)$$

Vertical (OY) direction:

$$\sum F_y = 0 \rightarrow N + F_{c'} - G_c - G_{k+m} = 0 \qquad (2)$$

Equilibrium of rotational moments:

$$\sum M_0 = 0 \rightarrow M_{Gc} + M_{Gk+m} - M_F = 0 \qquad (3)$$

Here, the moments are expressed as follows:

$$M = F \cdot d$$

here; d - shoulder distance relative to the center of rotation of the force *m*, $\theta$ - angle of rotation, F - effective value of the force *N*.

Dynamic loads act on the excavator boom during the process of lifting and lowering the load. [[16], [17]]. Dynamic loads are mainly caused by the following reasons:

- Inertial forces - steel wire change depending on the speed and acceleration of the rope:

$$F_{iner} = m \cdot a$$

-Oscillations and compression (tension) deformations - caused by the elasticity of the steel cable :

$$F_{pruj} = k \cdot \Delta l$$

Static load distribution on the boom in position 1

$$\sum F_k = 0, T_A + T_B - P = 0 \qquad (4)$$

$$T_A + T_B = P, T_A = P - T_B \qquad (5)$$

Taking into account elastic tension

$$\frac{T_A}{k_A} = \frac{T_B}{k_B} \qquad T_A = T_B \cdot \frac{k_A}{k_B} \qquad T_B = \frac{P}{1+\frac{k_A}{k_B}} \qquad (6)$$

We add the inertial forces for the dynamic state.

$$F_1 = m \cdot a \qquad (7)$$

$$T_A(t) + T_B(t) = P(t) + m \cdot a(t) \qquad (8)$$

here; $T_A$-strength of the right rope *N*, $T_B$-strength of the left rope *N*, $k_A$-rigidity of the right rope, $k_B$-rigidity of the left rope, P-all forces of gravity arising *N*, $F_{iner}$ -inertial force *N*, $F_{pruj}$ -elastic force arising in the rope *N*, $\Delta l$ -relative elongation of the rope *m*.

In this case, it is modeled by differential equations of oscillation. However, this can lead to two reasons:

1- dynamic resonance occurs when steel cables differ in stiffness and length;

2- If one of the steel cables stretches longer than the other, this causes the boom to deflect.

As a result of the load on one rope for such reasons, we obtain the following expression.

$$\Delta L = \frac{T}{k_A}, \; k_A = \frac{E_A}{L_A} \qquad (9)$$

If steel cable A stretches by 5 cm, then steel cable B needs 5 cm to stretch. In this case, according to expression (4)

$$ma(t) = T_A(t) + T_B(t) - P(t) \qquad (10)$$

The force of inertia arises.

$$ma(t) = k \cdot \Delta x, \quad ma(t) = k \cdot d\vartheta \cdot dt \qquad (11)$$

$$k \cdot \vartheta(t) = T_A(t) + T_B(t) \qquad (12)$$

In such cases:

1 - steel cable can quickly wear out and break;

2-a one-sided deflection of the arrow;

3- malfunctions occur based on static (1) and dynamic (4) expressions.

where; v-relative velocity arising on the rope, m-rope mass, a-rope acceleration, t-time.

The equations of static equilibrium and moment equilibrium are used to check the state of the boom [18].

## Discussion of the results

Figure 3 shows the change in the tension forces generated in the left and right steel wire ropes over the operating time, which shows the imbalance of the tension forces in the two steel wire ropes. This, in turn, causes the rapid failure of the excavator working members. In addition, due to exploitation and improper installation, it can also affect the efficiency of the excavator working members and the safety of the service personnel.

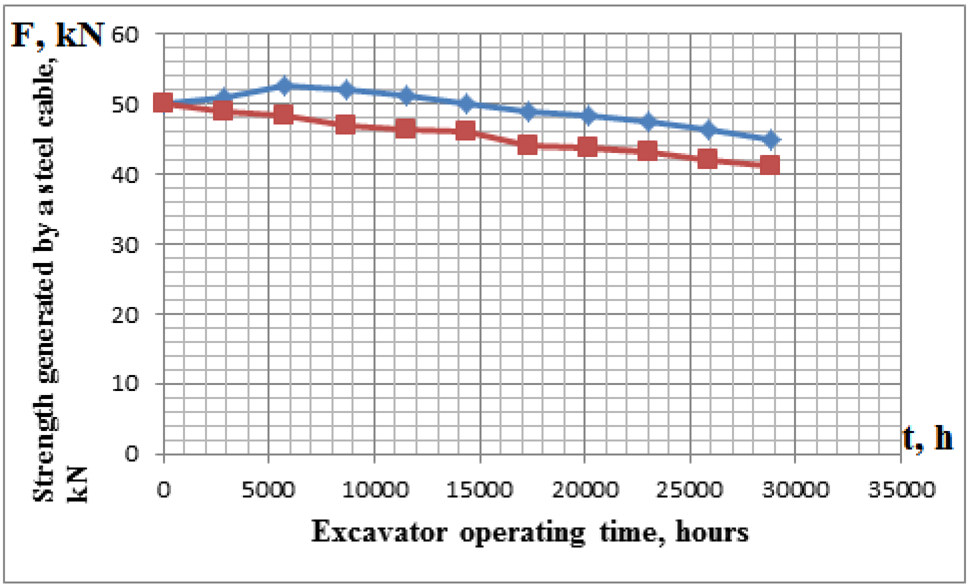


**Figure 3 -** Variation of tensile forces over time in the left and right steel wire ropes of the excavator boom. *Simulation results obtained using COMPAS-3D software. Horizontal axis – Time (t), s; Vertical axis – Tensile force (F), N.*

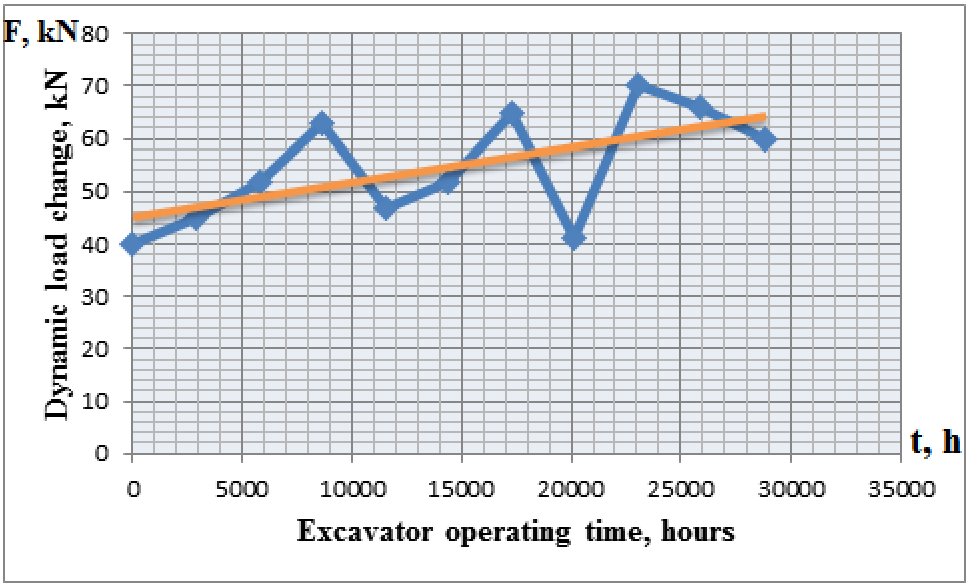


**Figure 4 -** Dynamic load variation on the excavator boom caused by imbalance in tensile forces of steel ropes. *Results obtained via finite element method (FEM) analysis. Horizontal axis – Time (t), s; Vertical axis – Dynamic load ($F_{dyn}$), N.*

During the operation of excavators, a dynamic load is created on the working parts. The formation of such a dynamic load changes over time. Figure 4 shows the change in the dynamic load on the excavator boom due to the difference in the tensile forces of the steel cables on the left and right sides of the excavator boom, where the main straight line is in normal operating conditions, and the dynamic load on the excavator boom changes due to the difference in the tensile forces of the steel cables on the left and right sides. In this case, the excavator's operation leads to the rapid failure of the boom.

As a new constructive solution, methods for reducing disproportions and dynamic loads arising in steel cables are presented. Figure 5 shows the view of the structure with a half-block installed on both supports of the excavator. Then 1-main block; 2-polar cable between the boom and two supports; 3 - upper section of the boom; 4 - lever; 5-two supports; 6 - half-block; 7 - lower sections of the boom. As a result of theoretical calculations, as a result of automatic correction and adjustment of the imbalance in steel cables, the tension forces and dynamic loads on the excavator boom are brought to a normal level. As a result, high efficiency is achieved due to the efficiency of the excavator boom and steel cables, as well as savings in operating time and repair time [[18], [19]].

Cable material: 52.0 G-V-O-N-160 ($\sigma_i$ = 1400 MPa, E = 2.1·$10^5$ MPa)

Cable diameter: ϕ = 52 mm

Boom length: L = 6.8 m

Boundary conditions: fixed support at base, pinned connection at top.

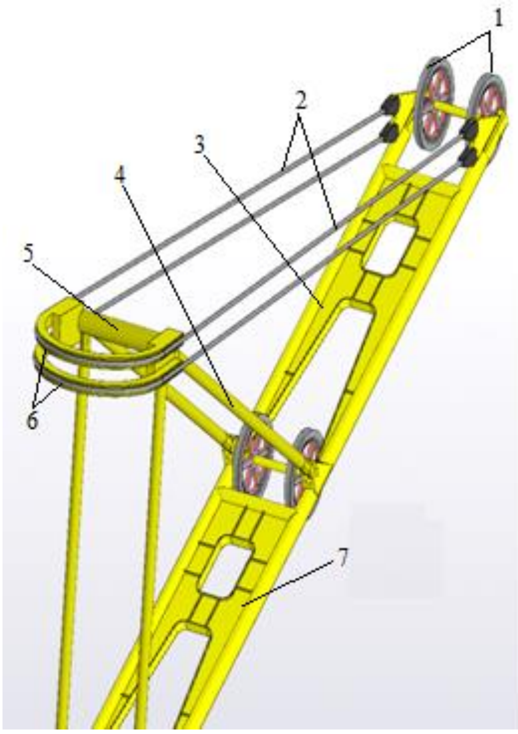


**Figure 5 -** View of the structure with a half-block installed on the two supports of the excavator

*1 - main block; 2-polar cable between the boom and two supports; 3 - upper section of the boom; 4 - lever; 5-two supports; 6 - half-block; 7 - lower section of the boom;*

In case 2, to resolve the issue:

$$\sum F_k = 0 \quad ma(t) = 0 \tag{13}$$

We accept the terms.

$\sum F_k \neq 0$ case, $F_q \neq 0$ condition is generated.

$F_q \neq 0$ this occurs when additional external forces arise (in vibrations, resonance, and mechanical oscillations).

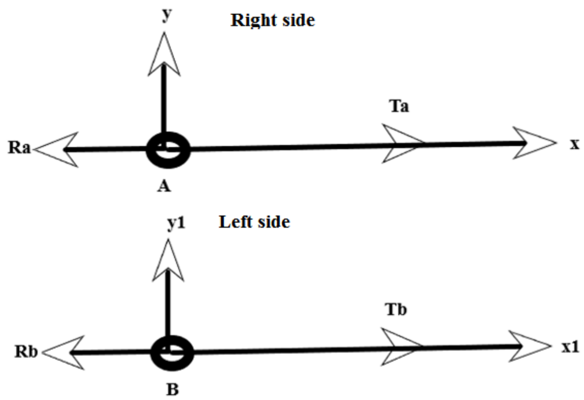


**Figure 6 -** Tension forces arising on the steel wire rope of the excavator boom: a) tension in right cable; b) tension in left cable

Through the semi-block system, the forces acting on the left and right wire ropes are automatically equalized. This balances the disproportionate loads that arise from any differences in length or stiffness of the ropes during movement [[20], [21], [22]].

The tensile forces arising in the steel cables of the excavator boom shown in fig. 6 are obtained using the following expressions (14), (15) and (16).

$$\sum F_x = 0, -R_A + T_A = 0 \tag{14}$$

$$\sum F_{x1} = 0, -R_B + T_B = 0 \tag{15}$$

$$R_A = T_A \qquad R_B = T_B \qquad T_A \neq T_B \tag{16}$$

here; $R_A$-reaction force of the right rope,
$R_B$-left rope reaction force.

According to the structural rules about static bonding and their reactions, the bonding reaction consisting of a taut thread is directed along the tension of this thread. Based on this, we have the following constructive solution to maintain the same tension of the steel cable and equalize the reaction force counteraction.

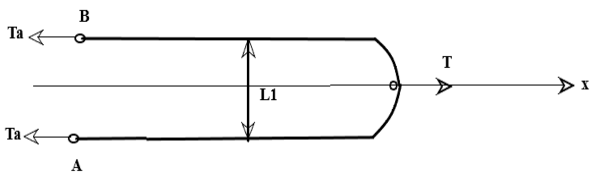


**Figure 7 -** Excavator boom tension forces

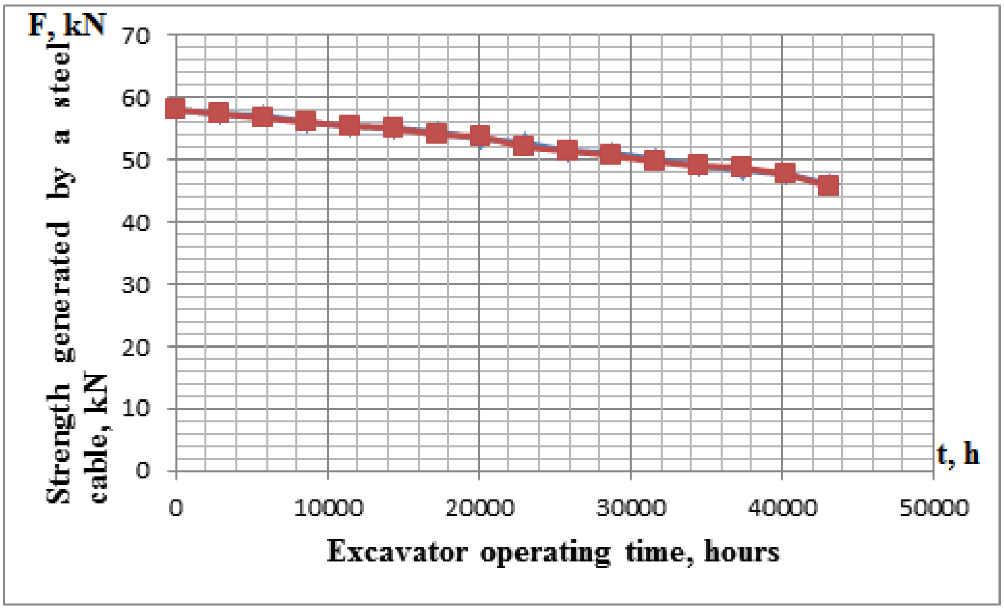


**Figure 8 -** Graph of the dependence of tensile forces on time on the left and right steel cables of the new design

The tension forces generated by the excavator boom shown in fig. 7 are determined by the following expressions (21), (22), (23) and (24) and we accept the conditions.

$$\sum F_x = 0, T_A + T_B - T = 0 \quad (17)$$
$$\sum M_A(F_k) \neq 0, -T \cdot \frac{l_1}{2} + T_A \cdot l_1 = M_A \quad (18)$$
$$\sum M_B(F_k) \neq 0, -T \cdot \frac{l_1}{2} + T_B \cdot l_1 = M_B \quad (19)$$
$$\sum M(F_k) = 0, M_A - M_B = 0, M_A = M_B \quad (20)$$

$M_A = T_A \cdot l_1, M_B = T_B \cdot l_1, T_A \cdot l_1 = T_B \cdot l_1 T_A = T_B$ condition is accepted.

In this case, an external inertial force arises, according to expression (4).

$$T_A(t) + T_B(t) = P(t) + ma(t) \quad (21)$$
$$F_x \neq k \cdot \Delta x = k \cdot d\vartheta \cdot dt \quad (22)$$
$$\Delta x = 0, d\vartheta = 0, \quad (23)$$
$$2T_A(t) = P(t) + ma(t) \quad (24)$$
$$2T_A(t) - P(t) = ma(t) \quad (25)$$
$$a = \frac{d\vartheta}{dt}, d\vartheta = 0, \quad (26)$$

$2T_A(t) = P(t)$ causes uniform load distribution.

here; *dv*-rope speed change,
$\Delta x$-change in rope length,
$M_A$ - right rope torque,
$M_B$-left rope torque.

The beneficial outcomes achieved based on the proposed model are presented in Table 2 below.

**Table 2** - The difference from previous scientific research

| Parameters | Before | Suggested system | Change (%) |
|---|---|---|---|
| Rope tension (max) | 18.4 kN | 12.9 kN | 29.8 % |
| Dynamic load peak | 16.2 kN | 8.1 kN | 50 % |
| Service life | 14 month | 19 month | 35.7 % |

In Figure 8, shows the dependence of the tension forces arising from the use of the new design solution on the left and right sides of the boom steel cables on the operating time of the excavator.

## Conclusion

If the steel wire ropes of excavators of the EKG-8I, EKG-10 and EKG-15 types do not have the same tension, an imbalance of moments will occur, which will lead to uneven positioning of the boom. It is necessary to identify and eliminate this problem in advance by calculating the balance of moments and forces based on the equations. During maintenance, the efficiency of operation will increase by regularly checking the cables, pulleys and reaction forces. In addition, by using the new design considered above, the efficiency of the excavator's working members will increase by 20-25% due to the efficiency of their work and the time spent on work and repairs. As a result of preventing unbalanced loads, the probability of failure of steel wire ropes will be reduced by 40-50%. Real-time monitoring of dynamic loads will reduce the risk of accidents by 30-40% and reduce maintenance costs by 20-25%. Overall, these solutions lead to a 25-35% increase in excavator efficiency and significant improvements in service life and safety. The results of the study show that the boom of single-bucket mining excavators used in the mining industry and steel cables between the two supports improve reliability and reduce maintenance costs.

**Conflict of interest.** On behalf of all the authors, the correspondent author declares that there is no conflict of interest.

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Қабылданды: *21 шілде 2025*

**ТҮЙІНДЕМЕ**
Мақалада бір шөмішті карьер экскаваторларының жебе элементіне және екі тірек арасындағы болат арқандарға әсер ететін динамикалық жүктемелер талданып, оларды азайтуға арналған конструкциялық шешімдер ұсынылған. Жебе мен болат арқандар әр жақта жеке орналасқан жағдайда, бір жақтағы арқанның тартылу күші артады, бұл тек сол жақтағы арқанға динамикалық әсер етіп қана қоймай, сонымен қатар жебенің майысуына әкеледі. Зерттеу әдістері ретінде статикалық және динамикалық жүктемелердің таралуына арналған тепе-теңдік теңдеулері мен соңғы элементтер әдісі қолданылды. Бағдарламалық модельдер негізінде жебе мен екі тіректің жаңа конструкциялық сызбасы жасалып, есептеу нәтижелері талданды. Екі тірекке жартылай блок түрінде орнатылған болат арқандар арқылы экскаватор жебесінің жаңа конструкциялық моделі жасалып, тартылу күшінің біркелкі таралуы мен автоматты тепе-теңдігі қамтамасыз етіледі. Бұл динамикалық жүктемелерді төмендетіп, жұмыс механизмдерінің қызмет ету мерзімін арттырады, сондай-ақ нақты уақыт режимінде арқандардағы жүктемелерді бақылау арқылы жұмысшылардың қауіпсіздігін қамтамасыз етеді. Мақаланың практикалық маңыздылығы – екі тірекке жартылай блок орнату арқылы экскаваторлардың сенімділігін арттыру, техникалық қызмет көрсету шығындарын азайту, жебедегі сызаттардың пайда болуына жол бермеу болып табылады. Арқандардағы жүктеме балансын қамтамасыз ету жұмыс механизмдерінің шамадан тыс жүктелуін болдырмайды, болат арқандардың қызмет ету мерзімін 15–20%-ға арттырады.

***Түйін сөздер:*** экскаватор, болат арқан, жүктеме, динамикалық теңгерім, статикалық теңгерім, құрылымдық шешім, пайдалану, техникалық қызмет көрсету, секция.

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# Методы анализа и снижения динамических нагрузок на стальной канат, удерживающий стрелу экскаваторов с канатным приводом


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**АННОТАЦИЯ**

В статье проведён анализ динамических нагрузок, действующих на стрелу одноковшовых карьерных экскаваторов и на стальные тросы, расположенные между двумя опорами. Предложены конструктивные решения, направленные на снижение указанных нагрузок. Показано, что при отдельном размещении стрелы и стальных тросов по обе стороны, натяжение троса с одной стороны приводит к его усиленной нагрузке, что оказывает не только динамическое воздействие на трос, но и вызывает изгиб стрелы. В качестве методов исследования использованы уравнения равновесия для распределения статических и динамических нагрузок, а также метод конечных элементов. На основе расчетов разработана новая модель конструктивного расположения стрелы и двух опор, проведен анализ полученных результатов. Предложенная модель, в которой стальные тросы устанавливаются на двух опорах в виде полублока, обеспечивает равномерное распределение усилий натяжения и автоматическое балансирование, что снижает динамические нагрузки, увеличивает срок службы рабочих механизмов и способствует повышению безопасности труда за счёт мониторинга тросов в реальном времени. Практическая значимость работы заключается в том, что установка полублоков на двух опорах повышает эксплуатационную надежность экскаваторов, снижает затраты на обслуживание и предупреждает возникновение трещин на стреле. Обеспечение баланса нагрузок предотвращает перегрузку рабочих механизмов и способствует увеличению срока службы тросов на 15–20%.



***Ключевые слова:*** экскаватор, стальные канаты, нагрузка, динамический баланс, статический баланс, конструктивное решение, эксплуатация, обслуживание, секция.



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