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CONSTRUCTION AND METHOD OF ASSESSMENT AND RESEARCH OF THE PARAMETERS OF A LOAD-LIFTING WINCH WITH A SECTIONAL DISC DRUM

The object of the study is a load-lifting winch with a sectional-disc drum for single-row multi-layer laying of flexible elements, cargo cables and power cables, during their winding, electrically protected. The winch is intended for suspension and lifting and lowering of illuminated devices and equipment in closed rooms.

In the process of research (constructive development, determination and analysis of parameters), the problem of creating a winch design of the specified type with a qualitatively increased overall level of functionality is solved according to the indicators:

1) electrical insulation, compactness and necessary strength of fastening of flexible elements, lifting cables and power cables on the drum;

2) controllability of the drive: in transitional periods – to ensure smooth acceleration-stopping of the suspension; in the period of constant movement – to ensure a constant speed of the suspension during raising and lowering.

Electrical insulation between the power cable, the drum and other parts of the winch is created by using parts (discs) made of synthetic insulating material, for example, fiberglass, in the construction of the drum. Clamping of flexible elements between the disks in specially profiled C-shaped ring grooves, on the ends of the hub, of the disks ensures the necessary strength and compactness of the attachment. The smoothness of starting (stopping) of the drive and the constant speed of the suspension during the period of constant movement are established by adjusting the frequency converter in the drive control system according to the parameters determined by a specially developed methodology.

The obtained results, constructive solutions and methods of research (estimation and analysis) of winch parameters can be used in the design of the structure and adjustment of the control system of lifting devices of this type.

Keywords: *winch, lifting equipment, sectional drum, multi-layer winding, construction of insulating winch, fastening of cargo ropes on the drum.*

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1. Introduction

Modern sanitary standards and design solutions in the field of arranging the lighting of internal spaces of buildings and institutions of wide social use require the use of appropriate means of mechanization of lighting processes, including lifting winches for suspension and smooth movement of electric lighting devices and equipment. Normative requirements regarding the arrangement and safe operation of lifting winches of this type are set out in the relevant documents [1–4].

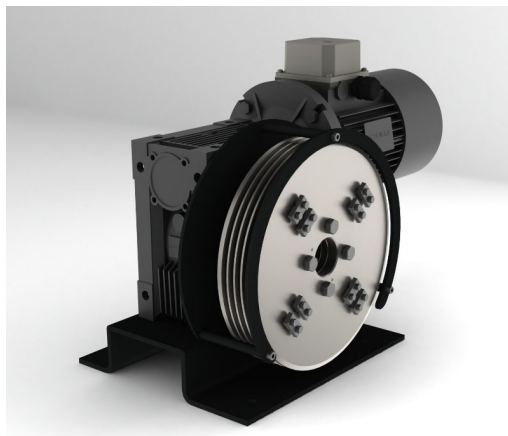
The analysis of existing structures [5], similar in purpose to lifting winches, carried out at the search stage revealed significant deficiencies in their structures and drive control systems, which negatively affect their functionality. This is an insufficient level of electrical protection of the structure, bulky and unreliable fastening of flexible elements on the drum, absence or insufficiency

of drive control systems to ensure smooth start-stops of the suspension and raising it at a constant speed during constant movement.

The presence of any of the listed defects in the design of the winch negatively affects its safety and the quality of its functions. The limited availability and inconsistency of the quality of performance of functions with modern requirements determine the urgency of conducting research (constructive development, creation of evaluation methods and parameter analysis) of winches of this type (Fig. 1).

Structurally, the winch (Fig. 1, *a*) consists of: an asynchronous alternating current drive motor with a short-circuited rotor, a reducer arranged with the motor according to the motor-reducer scheme; sectional disk drum for winding flexible elements: cargo cables and power cables; restrictive devices and control system; built-in double brakes.

Fig. 1, *b* shows an example of the use of a winch for controlled movement, lifting and lowering, decorative lamps.

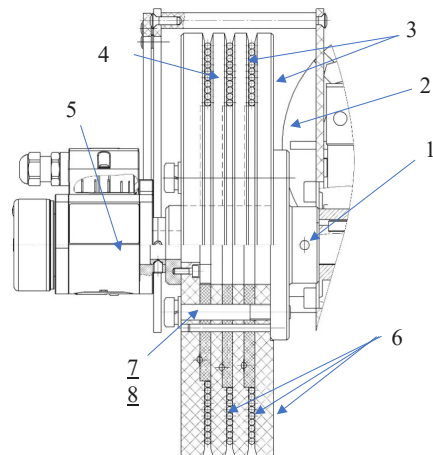


a

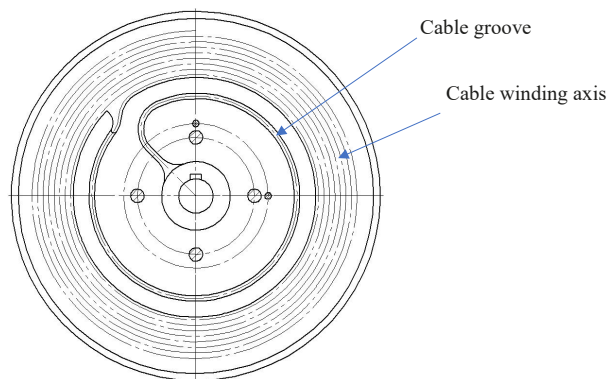


b

Fig. 1. General view of the winch:
a – 3D model; b – an example of application [6]



a



b

Fig. 2. Construction: a – drum: 1 – flange; 2 – internal disc; 3 – intermediate disks; 4 – external disk; 5 – current collector; 6 – rope/cable; 7, 8 – bolt, washer; b – appearance of the internal disc

The cable drum of the sectional-disc type (Fig. 2, a) is designed as a set (package) of specially designed discs fastened with tension bolts. Each individual disk (Fig. 2, b) has a thickening, a hub, with a hole in the center. On the end surfaces of the mutual abutment of the disks, milled annular C-shaped grooves for laying and clamping the cargo cable or power cable when assembling the drum structure. The profile of the groove in the section perpendicular to its axis of symmetry corresponds to the shape and dimensions of the profiles of standard elements (parts) for fastening steel cables and ropes. Disks are made of high-strength and heat-resistant synthetic dielectric material [7], for example, fiberglass, which will ensure the necessary level of interaction of the insulation of the winch design elements and the power supply. The central holes in the discs, when they are connected in a sectional-disc drum, form a cylindrical cavity in the central part of the drum, through which the ends of the power cables are brought out to the movable contacts of the ring current collector, fixed on the outer disc of the drum (on the left). The stationary contacts of the current collector are attached to the body (frame) of the winch.

The sectional-disc design of the cable drum developed in this way creates the possibility of separate electrically isolated laying of several strands of the cargo cable and the power cable of the lighting device in separate sections of the drum.

Sectional separation and accumulation on the drum of flexible elements of the suspension and power supply ensures a strictly vertical trajectory of the movement of the lighting device on the suspension.

Electrical insulation between the power cables, the drum and other parts of the winch is created thanks to the use of parts (discs) made of insulating material and a ring current collector in the construction of the drum.

The aim of the study was to determine the regularities of the speed change during multilayer winding and to study the transition periods, which is not fully described in [8] for this type of winches. The results of the research, in the future, will be used to increase the overall level of controllability of the drive: in transitional periods and the period of constant movement and the development of a unique design.

2. Materials and Methods

Let's present a generalized methodology for calculating parameters and selecting structural elements of a winch with a sectional disk drum.

The cargo cable is selected according to the calculated breaking force $F_{b.f.}$, N [8]:

$$F_{b.f.} = n_T F_T, \tag{1}$$

where n_T – safety factor of the cargo cable, according to the regulatory document [3], $n_T = 10$; F_T – tension force of one branch of the cable when lifting the load, N:

– when stocking the cable without using pulley system:

$$F_T = \frac{Qg}{z}, \tag{2}$$

– when using pulley system:

$$F_T = \frac{Qg}{z\eta_p}, \quad (3)$$

where z – the number of rope branches in the suspension;
 η_p – efficiency ratio pulley system.

When taking into account the dynamic component of the load's inertial force F_i , N, during the start-up period of the winch engine for lifting, equation (1) takes the form:

$$F_{b.f.} = n_T(F_T + F_i) = n_T(F_T + Q[a]), \quad (4)$$

where $[a]$ – regulated by normative documents [1–4] on the design of a winch of this type, the maximum permissible acceleration of the load, m/s².

Drum parameters:

– the minimum diameter of the cylindrical part, regulated [3], has the form:

$$D_1 = (e-1)d, \quad (5)$$

where e – coefficient, the value of which depends on the type and purpose of the lifting device, its mode of operation [9];
 d – diameter of flexible element, mm.

– the minimum diameter of the drum in the center of the winding of the flexible element:

$$D_d = D + d, \quad (6)$$

the actually adopted value D , is substituted into formula (6), mm;

– rope capacity of the drum (of its separate section/cavity):

$$L(i) = x\pi(D_1 + D_2 + \dots + D_i) = x\pi(D + d(i+1)) \geq h, \quad (7)$$

where $L(i)$ – estimated length of the flexible element that fits into one section of the drum, m; h – actual height of ascent, m; x – the number of turns of the flexible element in each i -th layer of the winding, in the design of the drum; $D_1 + D_2 + \dots + D_i$ – diameters of the drum on each i -th layer of winding of the flexible element, m.

In the design calculation from (7) is determined i – the number of working winding layers, after which the total number of layers is set i_{spare} , taking into account spare layers $i_{spare} = 1...2$ and fasteners $i_{fs} = 1...1.5$, in the construction of a sectional drum with a multilayer winding. After installation $i_{\Sigma} = i + i_{fs} + i_{spare}$, from (7) the final length of flexible elements is determined L , m.

Power of the drive electric motor, calculated, kW:

– during the period of constant movement:

$$P_{w.st.} = \frac{Qgv_1}{10^3 \eta_m}; \quad (8)$$

– during start-up (ascent):

$$P_{w.st.} = \frac{Q(g + [a])v_1}{10^3 \eta_m}, \quad (9)$$

where $g \cong 9.81$ m/s² – acceleration of gravity; η_m – efficiency factor of the mechanism.

For the selected engine, according to the calculated power $P_N \geq P_{w.p.}$, conditions are checked:

– during the period of constant movement:

$$T_N \geq T_{st.p.}, \quad (10)$$

or

$$9550 \frac{P_N}{n} \geq \frac{QgD_d}{2U\eta_m}, \quad (11)$$

where $T_N, T_{st.p.}$ – respectively, the nominal moment of the engine and the moment of resistance forces of the lifting load, reduced to the axis of rotation of the engine rotor, Nm; P_N – rated engine power, kW; n – rotor rotation frequency, rpm; D_d – diameter of the drum on the uppermost layer of the winding of the flexible element, m; U – gear ratio of the drive;

– during the period of constant movement:

$$T_{d.p.} \geq T_{av.p.}, \quad (12)$$

or

$$T_{st.p.} + T_{in.} \leq T_{av.p.}, \quad (13)$$

where $T_{in.}$ – the moment of inertia of the moving masses of the load and drive, reduced to the axis of rotation of the rotor, Nm. It is determined by the formula:

$$T_{in.} = I_{sp}\xi = I_{sp} \frac{2[a]}{D_d U}. \quad (14)$$

At the same time I_{sp} – reduced to the axis of rotation of the rotor, the moment of inertia of the moving masses of the cargo and the mechanism, kgm²:

$$I_{sp} = \delta I_r + \left(I_d \frac{\omega_d^2}{\omega} + Q \frac{v_1}{\omega^2} \right) \frac{1}{\eta_m}, \quad (15)$$

where I_r, I_d – moments of inertia of the motor rotor and drum, kgm²; δ – the coefficient that takes into account the approximate moments of inertia of the drive masses rotating with angular velocities lower than the angular velocity of the rotor, ω , rad/s; ω_d – angular velocity of the drum, rad/s; $T_{av.p.}$ – average starting torque, Nm:

$$T_{av.p.} = \frac{T_{p.max} + T_{p.min}}{2} = T_N \frac{\Psi_{max} + \Psi_{min}}{2} = T_N \Psi_{av}, \quad (16)$$

where $T_{p.max}, T_{p.min}$ – minimum and maximum engine starting torque, N; Ψ_{av} – average multiple of starting torque; Ψ_{min}, Ψ_{max} – multiples of starting moments:

$$\Psi_{min} = \frac{T_{n.min}}{T_N}; \quad \Psi_{max} = \frac{T_{n.max}}{T_N}. \quad (17)$$

Expressions (13) and (14) show that the value $T_{st.p.}$ varies in proportion to the diameter D_d , and the size $T_{in.}$, Nm, is inversely proportional (Fig. 3).

Let's show the general approach to the analysis of transient periods of movement using the example of the start-up period of the lifting mechanism. The equation of motion of the mechanism (13) for this period will be rewritten as:

$$T_{st.p.} + I_{ast} \frac{\omega_{av}}{[t]_p} \leq T_{st.p.} \quad (18)$$

where $[t]_p$ – the minimum allowable start-up time of the drive from the condition of ensuring the fulfillment of the condition $a_p \leq [a]_p$, s; ω_{av} – the average speed of the rotor during the start-up period;

$$[t]_p = \frac{v_1}{[a]_p} \quad (19)$$

From (18), rad/s:

$$\omega_p = \frac{[t]_p (T_{av.p.} - T_{st.p.})}{I_{ast} n} \quad (20)$$

When applied in a drive control system with an induction motor with a short-circuited rotor of a frequency converter, the control parameter is the frequency f , Hz input voltage; the circular frequency of the pulsation of the electromagnetic flux in the stator winding ω_p , rad/s, [10]. Input voltage frequency f , Hz and the number of pole pairs in the stator winding are related by the ratio:

$$\omega_p = \frac{\omega_{av}}{1-S} = \frac{2\pi f}{p} \quad (21)$$

where S – sliding (during start-up).

From (21):

$$f = \frac{\omega_{av} p}{2\pi(1-S)} \quad (22)$$

Size $T_{av.p.}$, Nm; $[t]_p$, s; f is the actuator control system setting parameters for the lift start period, Hz.

The parameters for the rest of the transition periods are similarly calculated: braking during ascent; launch for descent; braking when lowering. The values obtained as a result of the calculations are used when setting up the drive control system.

During the period of constant movement of the suspension up and down at a constant speed $v_1 = \text{const}$, the algorithm for changing the angular speed of the drum is determined ω_{d_i} , rad/s and the setting of the frequency converter is specified.

In accordance with the change in the diameter of the drum in the center of the winding of the rope D_{d_i} , m, the angular speed of the drum is determined:

$$\omega_{d_1} = \frac{2v_1}{D_{d_1}}, \omega_{d_2} = \frac{2v_2}{D_{d_2}}, \dots, \omega_{d_i} = \frac{2v_1}{D+d(i+1)} \quad (23)$$

Let's determine the difference in angular velocities, where the sign « \pm » accordingly, it depends on – the upward or downward movement is performed, rad/s:

$$\Delta\omega_{i,i} = \omega_1 \pm \omega_i = 2v \left(\frac{1}{D_{d_1}} \pm \frac{1}{D+d(i+1)} \right) \quad (24)$$

The duration of the period of steady motion, s:

$$t_{st} = \frac{h}{v_1} \quad (25)$$

Options to configure ω_{d_i} , rad/s and f_1 , Hz is determined using formulas (21), (22).

Disc brakes are selected according to the values of the estimated braking torque, Nm.

$$T_{br} = T_{r.br.} = k_{br} T_{st.br.} = k_{br} \frac{QgD_d}{2U} \eta_m \quad (26)$$

where k_{br} – braking reserve factor, the value of which depends on the operating mode of the mechanism, $k_{br} \geq 2$.

According to the requirements of regulatory documents [1–4], the winch is equipped with double disc brakes built into the engine.

3. Results and Discussion

According to the described methodology for the calculation of a sectional drum with multilayer winding, the dependencies were determined $\omega_{d_i} = \omega_{d_i}(D_i)$ at $v_1 = \text{const}$ which are displayed on the graph (Fig. 4). Further use of these dependencies makes it possible with the help of algorithms of the control system to stabilize the speed and ensure the smoothness of movement on any layer of the winding.

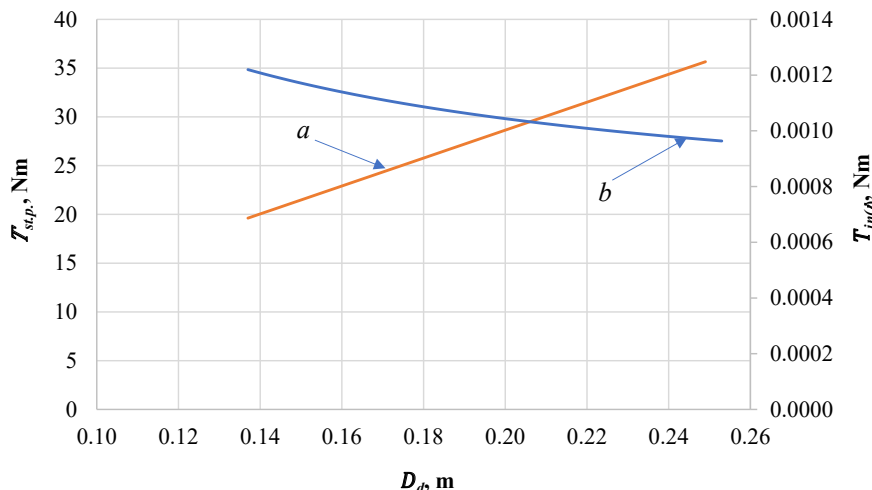


Fig. 3. Dependency graphs: $a - T_{st.p.} = T_{st.p.}(D_{i,t})$; $b - T_{in} = T_{in}(D_{i,t})$

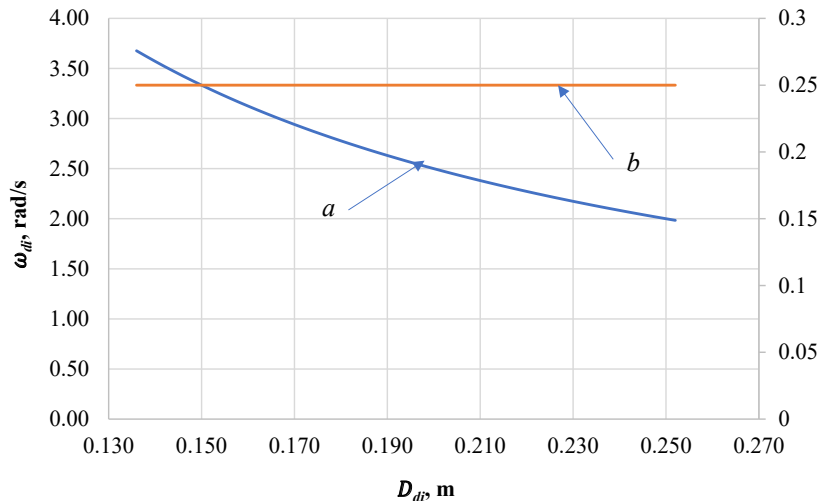


Fig. 4. Graphs of dependencies: $a - \omega_{di} = \omega_{di}(D_i)$; $b - v_1 = \text{const}$

Source analysis also identified the use of synthetic fiber cargo ropes, which have better performance in the deep sea. Such a solution could provide better insulation. However, according to the results obtained in [11], this application can seriously damage the winch structure, lead to an increase in the cost of the structure, and also contradicts the adopted state regulations.

As can be seen from the above results, the use of the above approach makes it possible to determine and record the law of motion, lifting/lowering the load, in the control system, which in turn stabilizes the speed $v_1 = \text{const} = 0.25$ m/s and smoothness of movement during multi-layer winding and diameter change $D_i = 0.132...0.252$ m.

The developed constructive solutions with multi-turn winding in one row and the results of the research (estimation and analysis) of the parameters of the winch of transitional periods can be used in the field of arranging dynamic lighting systems for the internal spaces of buildings and institutions of wide social use. They can also be used when setting up the control system of lifting devices of this type.

4. Conclusions

As a result of the study of existing structural developments, problem areas in the design and calculation methodology for winches with multilayer winding on a disc multi-section drum were identified and analyzed. A constructive solution of the drum design was also developed, which ensures electrical isolation of the drive mechanism, compactness and strength of fastening of flexible elements of lifting ropes and power cables on the drum, in comparison with existing designs on the market.

The calculation methodology for the selection of the drive was explained and applied, the analysis was made: in transitional periods – to ensure smooth acceleration-stopping of the suspension; in the period of constant movement – to ensure a constant speed of the suspension during raising and lowering.

The obtained results, constructive solutions and methods of research (estimation and analysis) of winch parameters were used in the design of the structure and adjustment of the control system of lifting devices of this type. Thanks to the settings of the control system, the smoothness of the movement and the constant speed/climbing are en-

sured $v_1 = \text{const} = 0.25$ m/s when changing the diameter $D_i = 0.132...0.252$ m. The described methodology can be interpreted to different size and load capacity of the presented type of winches.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this study, including financial, personal, authorship, or any other, that could affect the study and its results presented in this article.

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Data availability

Data will be provided upon reasonable request.

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