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Article

Using Recurrent Procedures in Adaptive control System for Identify the Model Parameters of the Moving Vessel on the Cross Slipway

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Abstract: The article analyzes the problems connected with ensuring the coordinated operation of slipway drives that arise during the launch of a ship. The dynamic model of load of the electric drive of the ship's cart is obtained taking into account the peculiarities of the construction of the ship-lifting complex, which allows to analyze the influence of external factors and random influences during the entire process of launching the ship. A linearized mathematical model of the dynamics of a complex vessel movement in the process of descent in the space of states is developed, which allows to identify the mode of operation of the multi-drive system, taking into account its structure. The analysis of efficiency of application of recurrent methods of identification (stochastic approximation and least squares) of the parameters of the linearized model in the space of states is carried out. A decision support system has been developed in the automated system of operational control by the module for estimating the situation and the control synthesis to ensure a coherent motion of a complex ship-carts object in a two-phase environment.

Keywords: slipway, adaptive control system, the method of least squares, procedure periodic, parameter estimation, large-sized object, a recurrent algorithm, the identification procedure

1. Summary

Shipbuilding and ship repair are one of the most important sectors of the economy in countries with access to the sea or which have large river systems. Depending on the technology of the construction of vessels, as well as their size and purpose, different facilities for moving ships to and from the water are used [1].

The slipways make up about 30% of all existing boat launch systems and apply to 60% of shipbuilding facilities. Most slipways, for example in the CIS countries, were built in the 60's and 80's of the twentieth century. The main problems of these facilities people are the use of outdated control systems on the one hand and their considerable deterioration on the other, which entails a number of difficulties during the operation of the launching facilities. The ship-lifting facilities are a complex electromechanical system. For the operational control it is advisable to use the means of automated systems. The type of slipway complex is presented in Figure 1.

For descent or ascent using a slipway, the vessel is mounted on special carts 1, which move along rail tracks 2 located on an inclined plane at an angle of 6 ° - 10 °. Each cart is driven by a single electric drive 3 using a steel cable 4. Carts have the ability to independently move down along the rails down (up), while the main task during the descent (lifting) of the vessel 5 is the coordinated movement of carts, in which the vessel should move uniformly at a given speed without distortions.

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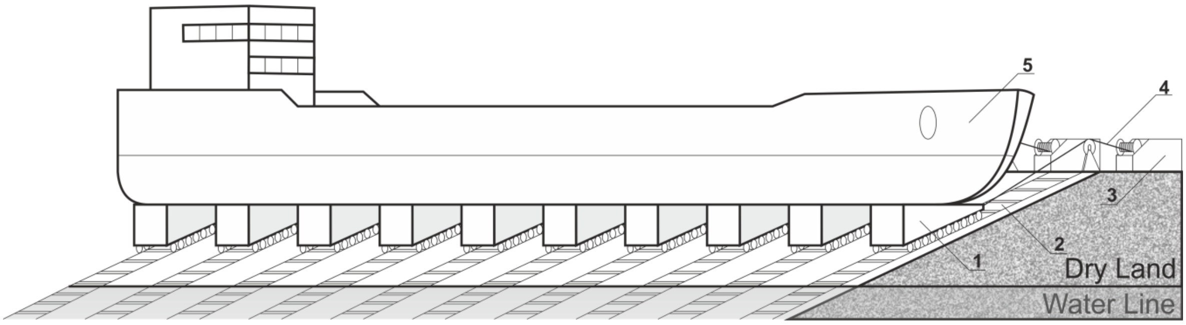

Figure 1. Cross slipway: 1 - carts; 2 - rail tracks; 3 - electric drives; 4 - cables; 5 - vessel.

The process of launching the ship can be divided into several stages (Figure 2):

1. The movement of the cart with acceleration to the necessary constant mode speed of descent, $l \in [0, l_1]$.

2. The movement of the cart at a constant speed before entering the water, $l \in [l_1, l_2]$.

3. Transfer of the cart from the slip surface to the underwater part, $l \in [l_2, l_3]$.

4. Full submersion carts under water, $l \in [l_3, l_4]$.

5. The movement of the cart at a constant speed in the water before the vessel ascends, $l \in [l_4, l_5]$.

6. The ascent of the ship and the braking of the cart to a full stop, $l \in [l_5, l_6]$.

Control of the motion parameters of the trigger car must be carried out throughout the journey.

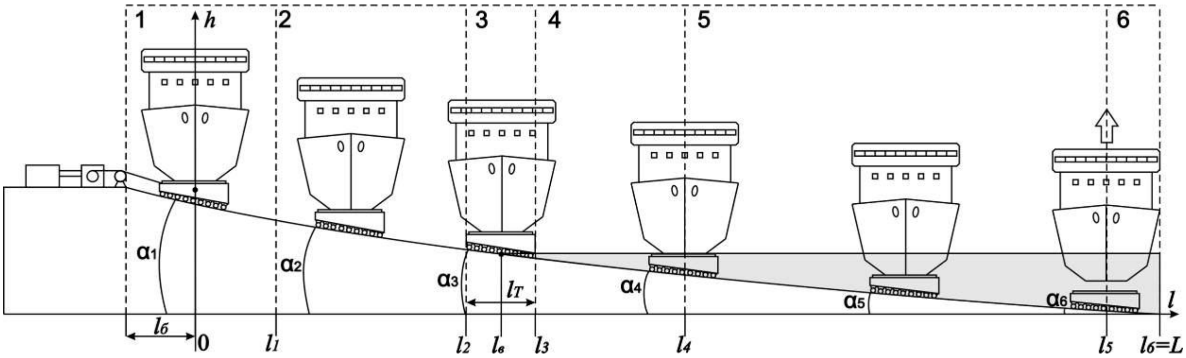

Figure 2. Stages of launching the vessel using a slipway

Despite the existence of regulatory rules for the technical operation of ship-lifting facilities, describing step by step the necessary sequence of actions during preparation and vessel launching, the emergency situations are occurred periodically. The main reason for this is the uneven load on the electric drives, and, accordingly, the overload of electric motors and cables.

The overhaul of the ship-building facilities implies substantial financial costs, while the cost of modernizing the control system is several orders of magnitude lower.

The movement of large-sized objects is carried out through the interconnected operation of electric drives and mechanisms complex. The processes of displacement occur under non-stationary conditions under the influence of external factors, which change significantly throughout the movement, which often leads to the occurrence of emergencies. Reliable functioning of such complexes is possible only with the use of adaptive control systems under the influence of stochastically changing external and internal factors. The tasks of identifying the parameters of the displacement process model arise periodically in the synthesis of the electromechanical complexes components operation rational control.

Recently, the trend is to use artificial intelligence techniques to perform the identification process, such as fuzzy logic, neural networks, etc.

However, in order to use the neural network technology, it is necessary to use a high-volume training set for a teaching of the artificial intelligent system, which is not always possible, due to the lack of a data set for training or limited training time [2].

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In case using fuzzy systems, there is a problem creating a base of rules and membership functions, which is especially difficult in the conditions of an abrupt change in the factors that influence the process.

2. Data Description

For a uniform movement of the launching carts, as well as in the areas of its acceleration and deceleration, it is necessary to constantly provide the appropriate cable tension. The main forces acting to the cart during the descent are shown in figure 3.

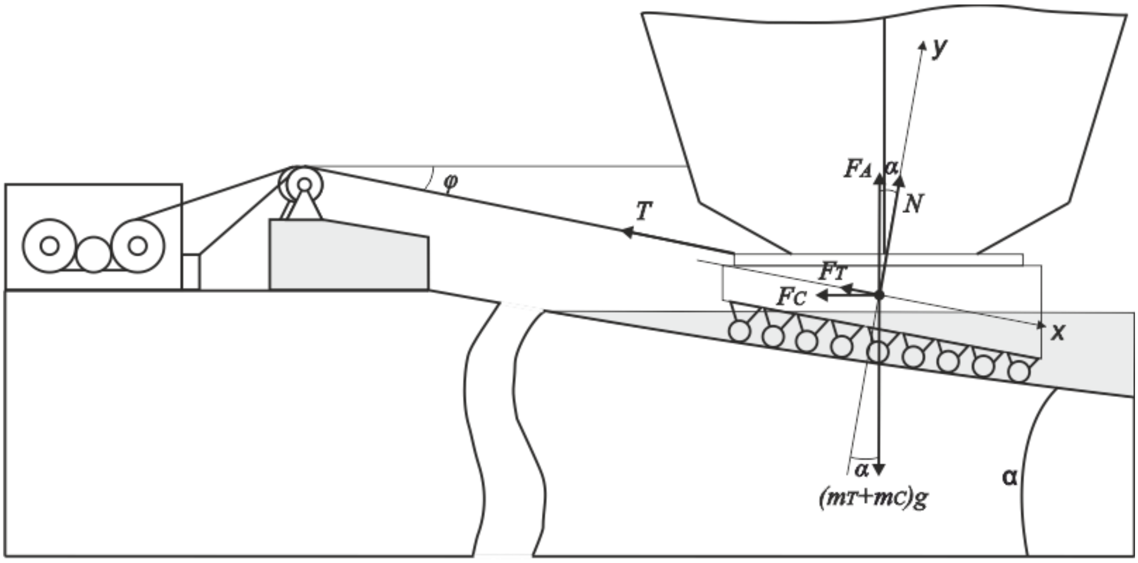

Figure 3. Forces that acting to the cart during the launch of the vessel

Using the second law of Newton, we will create a system of equations for a cart with a ship mounted on it, taking into account all the forces acting on the cart along the entire path (both by land and in water):

$$\sum F_x = (m_T + m_C)g \cdot sin(\alpha) - T \cdot cos(\phi - \alpha) - F_T - F_C \cdot cos(\alpha) - F_A \cdot sin(\alpha) = (m_T + m_C)a,$$

$$\sum F_y = N + T \cdot sin(\phi - \alpha) + F_A \cdot cos(\alpha) - mg \cdot cos(\alpha) - F_C \cdot sin(\alpha) = 0, \quad (1)$$

$$F_T = \mu \cdot N,$$

where m_T is the mass of the cart, m_C is the mass of the ship section, α is the slope angle of the slip; T - cable tension, ϕ - the deflection of the cable;
F_T - friction force, F_C - water resistance force, F_A - Archimedes force;
a - cart acceleration, μ is the coefficient of rolling friction between the wheels of the cart and the rails, N is the reaction force of the support.

Thus, from system (1) it is possible to express the tension of the cable T in the following form

$$T = \frac{((m_T + m_C)g - F_A) \cdot (sin(\alpha) - \mu \cdot cos(\alpha)) - F_C(\mu \cdot sin(\alpha) + cos(\alpha))}{\mu \cdot sin(\phi - \alpha) - cos(\phi - \alpha)}. \quad (2)$$

The forces acting on the cart when moving in water (Archimedes force F_A and the resistance force from the water side F_C) have the form defined by the following relations:

$$F_C = k_c \cdot S \frac{\rho v^2}{2}, \quad (3)$$

$$F_A = \rho g V_п, \quad (4)$$

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where k_c is the coefficient of resistance of the vessel and the cart (for the central sections of the vessel, can be taken ≈ 1);
$S = S_C + S_T$ is the characteristic surface area of the vessel and cart, v - cart speed, ρ is the density of water;
$V_п = V_C + V_T$ is the volume of the vessel and the cart submerged in water.

Consider the dependence of all changing factors on the distance traveled l. In figure 4 shows the geometry of the object (slip), the ratio of its height and length.

The change in the height of the slip relative to its length can be described by the exponential dependence $h(l) = H \cdot e^{-\lambda l}$ or, taking into account a small change in the angle of inclination - $\alpha \approx 4°$ from the slip geometry can be found as

$$h(l) = H - l \cdot sin(\alpha), \quad (5)$$

where H is the height of the slipway.

In figure 4 shows the angle of inclination of the cable ϕ during the descent process without taking into account the extension of the cable.

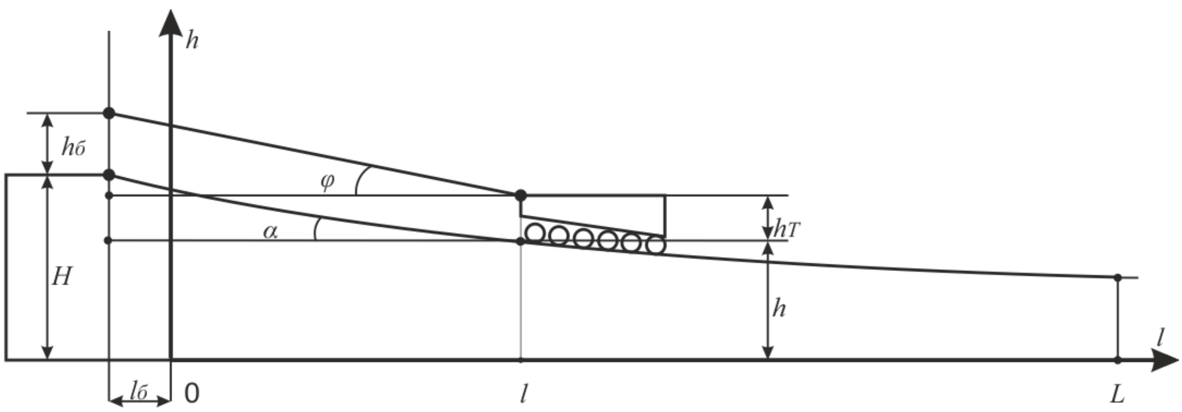

Figure 4. Graph of the angle of inclination of the cable ϕ

From geometric relationships, we can get the following relation

$$\phi = arctg\left(\frac{(H-h)+(h_б-h_T)}{l+l_б}\right), \quad (6)$$

where $h_б$ is the height of the block; h_T is the height of the cart; h - the current height of the cart; $l_б$ is the distance from the starting point of the cart to the point of the cable stop.

To take into account the impact on the object of Archimedes force, it is necessary to consider the change in the vessel and vessel submerged in water $V_п$, since, according to (4), $F_A = f(V_п)$. Due to the design features of the slip first, the cart will be submerged in water, which has a very small volume compared to the ship hull, then the lower, narrower part of the vessel enters the water, after which the volume $V_п$ will increase nonlinearly. In figure 5 shows the cart and section of the vessel when submerged under water and the dependence of the total submerged volume $V_п$ on l, where 1 is the surface part of the vessel, and zones 3 and 2 are the submerged part of the cart and vessel, respectively.

In figure 6, 7, 8 shows the different diagrams of submerged volume of the cart V_T and the vessel section V_C , in dependencies from the traveled path l.

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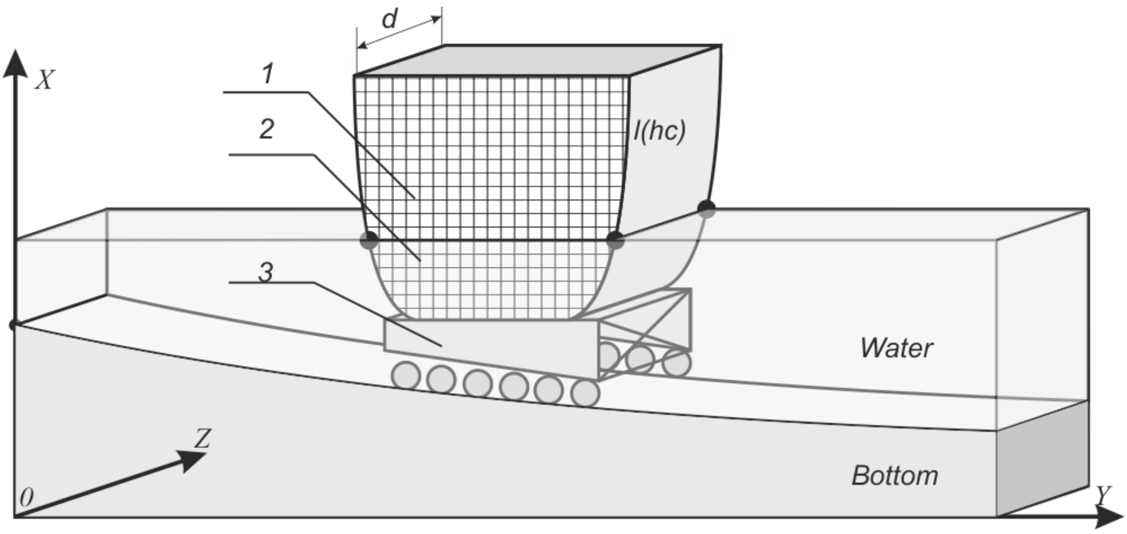

Figure 5. Visual cart and vessel section submerged volume change

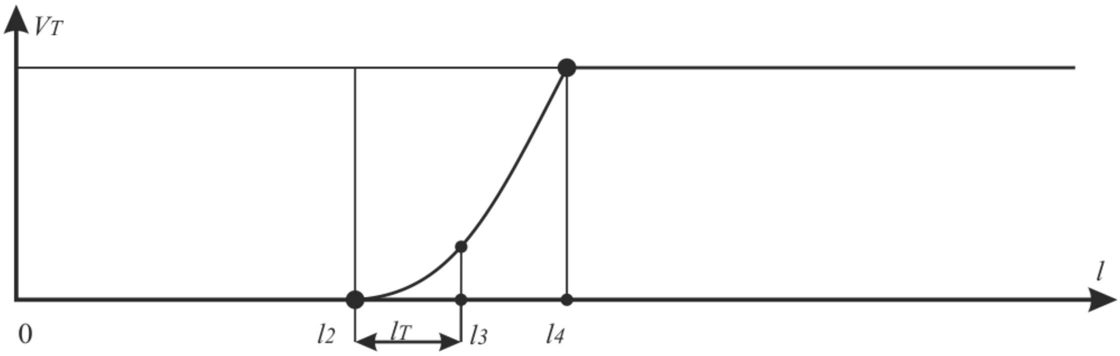

Figure 6. Diagram of cart submerged volume V_T change

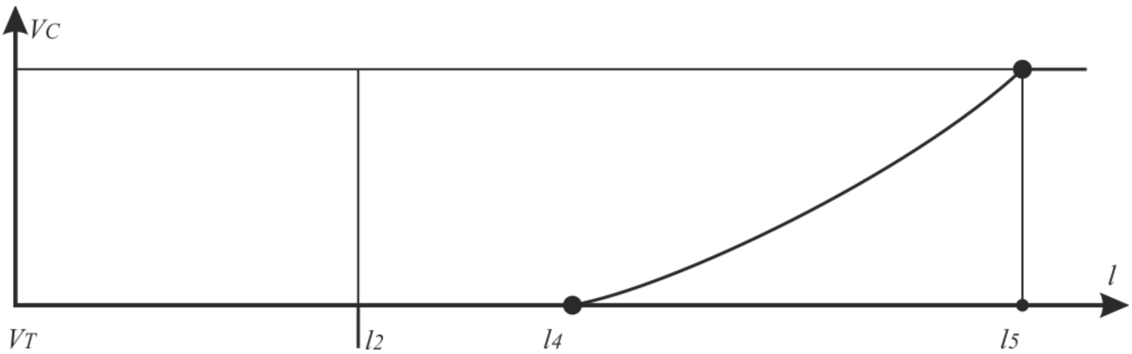

Figure 7. Diagram of typical vessel section submerged volume V_C change

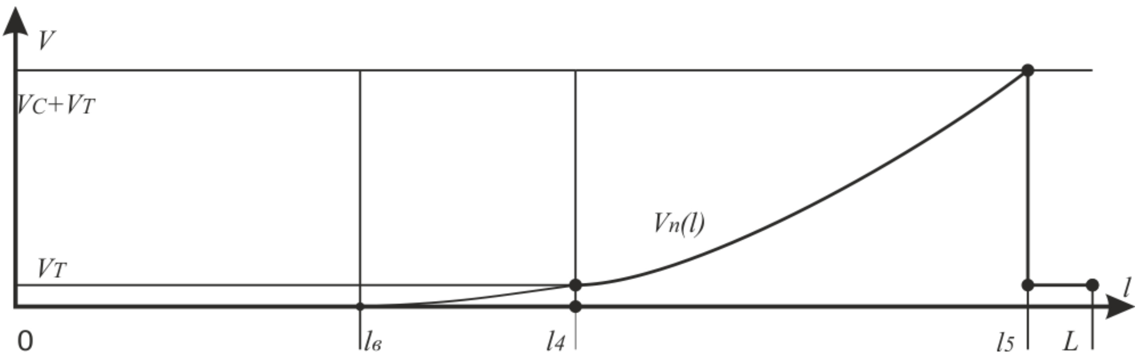

Figure 8. Diagram of cart and vessel section submerged volume change

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Thus, the impact of the buoyancy force can be predicted with the known law of volume change. Due to the fact that the volume of the launch of the submerged carriage is extremely small and the same for all carts, it can be neglected. The volume of the vessel section in Cartesian coordinates system can be calculated using the triple integral [3].

The characteristic area of the vessel is the area that is perpendicular to the flow of water. In this case, for the central part of the vessel, the characteristic area of the vessel is equal to the area of the rectangle formed by the length of section d and the height of the vessel h_v. If you neglect the characteristic area of the cart S_T you can write

$$S = h_v \cdot d. \tag{7}$$

The characteristic area S has an effect on the force of water resistance, and it becomes greater as the ship sinks deeper into the water, therefore, it depends on l. In figure 9 shows the dependence of S on the slip length l.

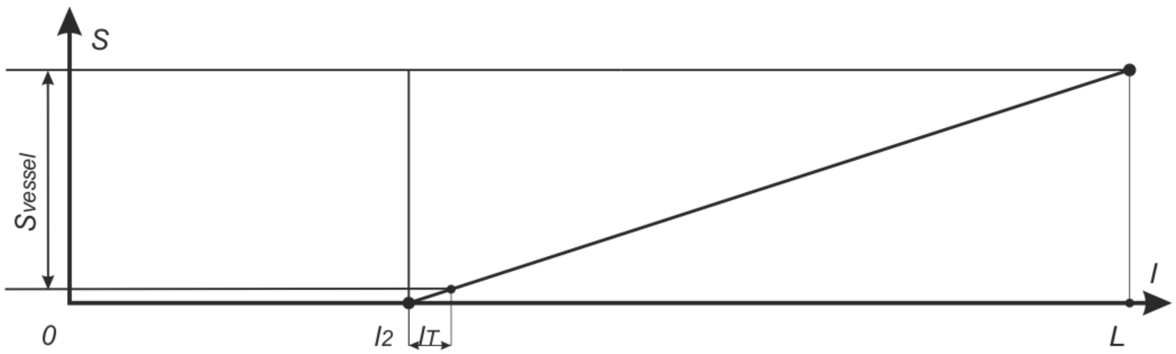

Figure 9. Changing the characteristic area of the vessel and carts while diving

The coefficient of friction μ when driving over land or water has constant values. However, when a cart enters the water (zone 3), it smoothly changes (Figure 10).

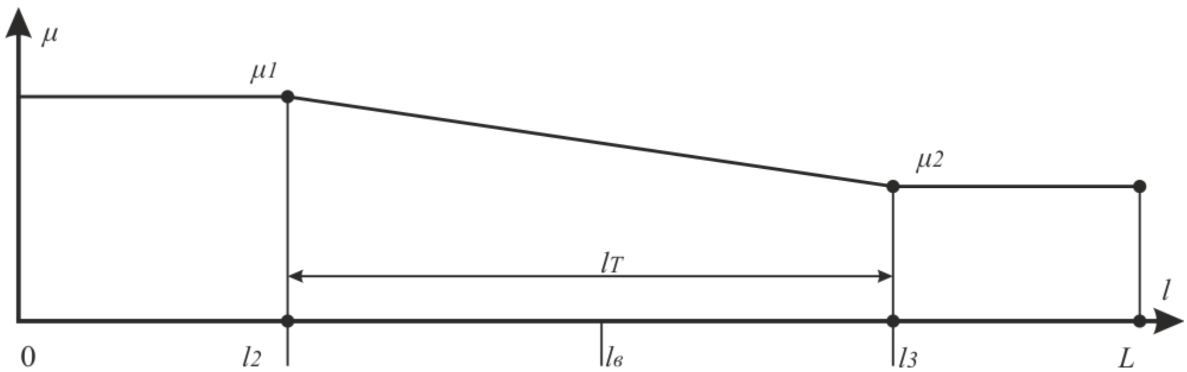

Figure 10. The change of the coefficient of rolling friction during immersion

To describe the dependence of μ on the path traveled, you can use z-shaped membership functions [4], which leads to the expression

$$\mu(l) = \mu_2 + \frac{\mu_1 - \mu_2}{1 + e^{\delta \cdot (l - l_B)}}, \tag{8}$$

where μ_1, μ_2 - coefficients of friction between the wheels of the cart and the rails on land and in water, respectively; δ is the coefficient of steepness.

The coefficient of slope δ is as follows

$$\delta = \frac{4}{l_T} \cdot ln\left(\frac{1}{\varepsilon} - 1\right), \tag{9}$$

where ε is the admissible error.

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Since the motion parameters in different zones are distinguished by the presence and magnitude of some forces and factors, for modeling it is necessary to set them accordingly, as shown above. Possible values of the parameters considered by zones are shown in Table 1.

Given specific values of the parameters, it is possible to obtain for them analytical dependencies based on relations (2) - (9) and to analyze the changes in the loads (forces) and parameters of interest when the trigger car moves along the entire length of the slip.

When analyzing the movement of the trigger carriage, it is necessary to take into account the change of parameters that affect the process of descent at all stages - from the beginning of movement to the stop.

The dependences and relations obtained allow us to determine the cable tension T depending on the given mode of motion (speed v_d, acceleration a_1 and deceleration a_2) throughout the entire route. This makes it possible to estimate the load on the electric drive during the descent process.

Table 1. Movement parameters at various stages of descent

Parameters	Zones					
	1	2	3	4	5	6
Cart weight, m_T	m_1	m_1	m_1	m_1	m_1	m_1
Ship section weight, m_C	m_2	m_2	m_2	m_2	m_2	0
Acceleration, a	$a_1 = const$, $a_1 > 0$	0	0	0	0	$a_2 = const$, $a_2 < 0$
Slipway slope angle, α	$\alpha(l)$					
Cable deflection angle, ϕ	$\phi(l)$					
Coefficient of friction, μ	μ_1	μ_1	$\mu_1 \div \mu_2$	μ_2	μ_2	μ_2
Cart area, S_T	0	0	$0 \div S_T$		S_T	S_T
Ship section area, S_C	0	0	0	0	$0 \div S_C$	0
Cart volume, V_T	0	0	$0 \div V_T$		V_T	V_T
Ship section volume, V_C	0	0	0	0	$0 \div V_C$	0
Speed, v	$0 \div v_d$	v_d	v_d	v_d	v_d	$v_d \div 0$

To optimize (match) the drive control of a complex electromechanical system for launching a ship into the "slipway" type, it is advisable to develop a dynamic model of the engine of the launching carriage in the state space based on equation (2).

The movement of a large object on a surface can be regarded as the sum of translational and rotational motions, which are described by equations with respect to the center of mass [4]:

– for translational motion

$$m\frac{dv}{dt} = \sum F, \frac{dl}{dt} = v, \quad (10)$$

– for rotational motion

$$J\frac{d\omega}{dt} = \sum M, \frac{d\phi}{dt} = \omega, \quad (11)$$

where m is the mass of the object, v is the speed of the translational motion, l is the displacement, t is the time, $\sum F$ is the sum of the external forces applied to the object, J is the inertia moment of the

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object relative to the axis of rotation, ω is the angular velocity of the object, ϕ is the angle of the object rotation, $\sum M$ is the total rotational moment of all forces with respect to axis of the mass center rotation of a large-sized object. A diagram for determining the parameters of motion for two points of measurement is shown in Figure 11.

The system of equations (10), (11) can be represented as equations in the state space of the fourth order [5] with state vector of the object being moved $\boldsymbol{x} = (x_1 \quad x_2 \quad x_3 \quad x_4)^T$, where $x_1 = S$, $x_2 = v$, $v = dS/dt$ $x_3 = \phi$, $x_4 = \omega = d\phi/dt$; vector of control actions **u** and output vector **y** characterizing the structure of the monitoring system. This systems model is, as a rule, non-linear dependencies.

In the synthesis of optimal control actions, the methods of modern control theory usually use the linearized model of system, represented in the state space [6].

To identify the parameters of the motion of a large object, which must be taken into account when controlling the mode of operation of the blind and the synthesis of drive control, it is possible to measure the distance of some points of the object when moved from their original position.

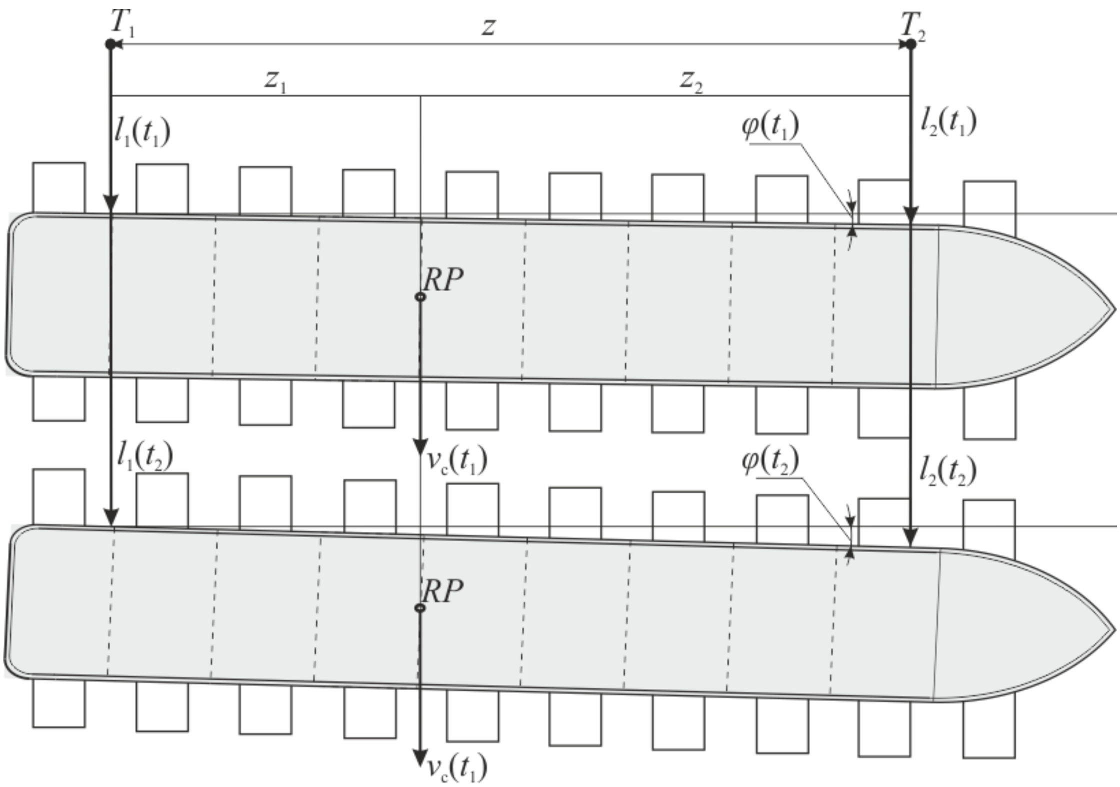

Figure 11. A scheme for determining the parameters of motion

One of the obvious solutions to the problem of ensuring a consistent movement of the launch trucks is to provide control over the position of the stern and bow of the vessel (Figure 12). Indeed, most of the problems arising from the launching of a ship on the track of the slip have a direct impact on the position of the ship. Due to the design of the slip, the misalignment of the movement of the carts (their position is not in an "even row") leads to a change in the position of the hull, its distortion and displacement.

Under slip operation conditions, the most acceptable technical characteristics are the use of optical location means, since it requires measurement in the open air in the range of 1 - 100 m ± 0.01. Given the shape of the hull of the vessel (Figure 13), it seems convenient to measure the distance to the hull using laser range finders.

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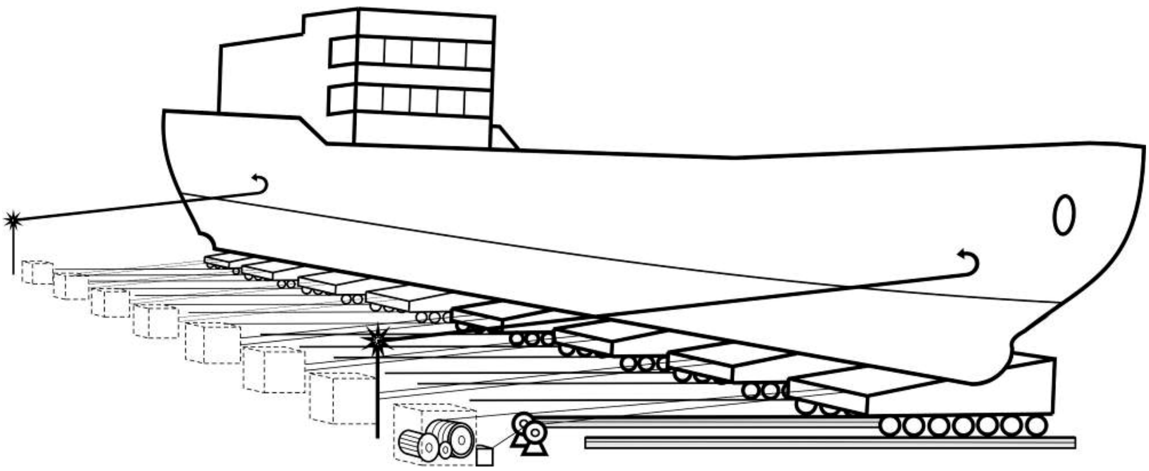

Figure 12. Control of ship movement with a range finder - general view

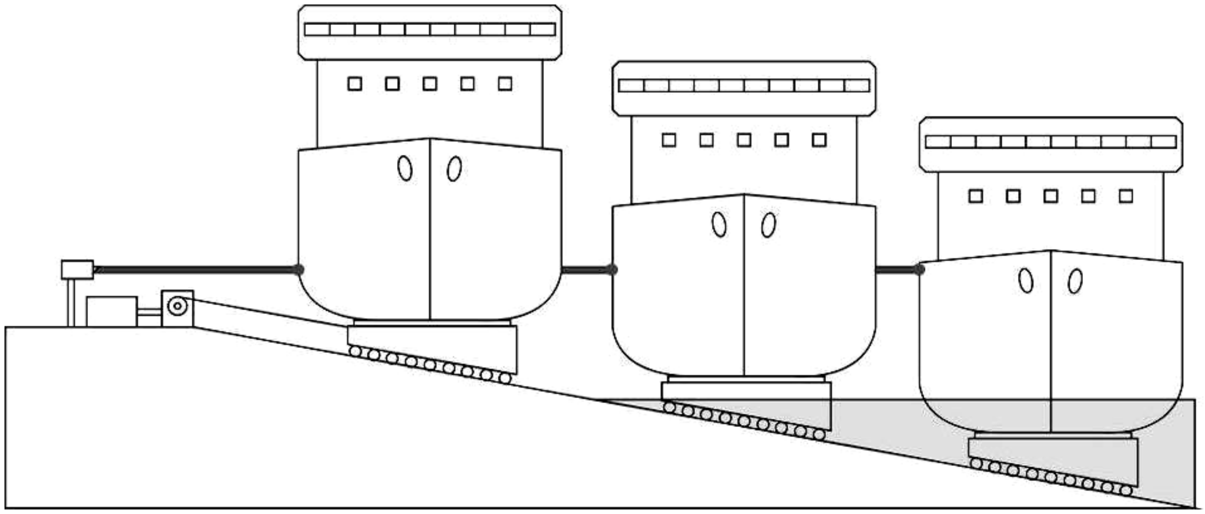

Figure 13. Control of ship movement with a range finder - side view

Consider the process of moving a bulky object by example of a ship's descent on a slipway. Forces acting on a distributed, moving "ship-carts" object during a controlled descent are shown in Figure 14.

The model of ship movement on a slipway, developed in the states space, which takes into account all the significant external factors, is nonlinear [7].

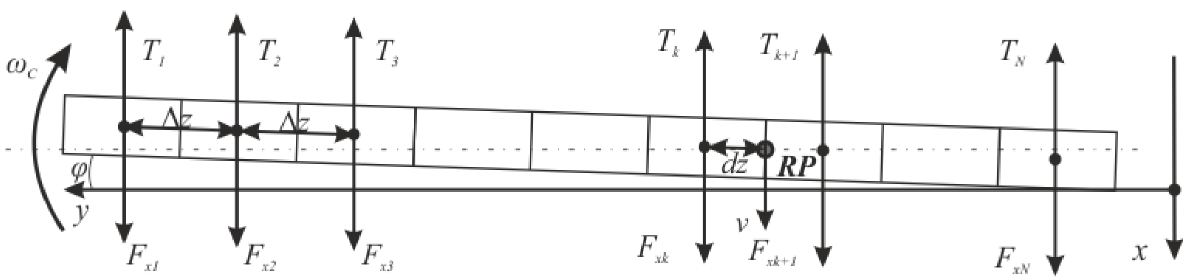

Figure 14. The structure of forces acting on the "ship-carts" object

Based on the analysis of the equations of motion, the equations of state of the model of the ship-cart object are formulated in the state space in the form

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$$\dot{x}_1 = x_2,$$
$$\dot{x}_2 = \frac{1}{m}\sum_{i=1}^{N} F_{xi}(x_1) - \frac{T_m}{m}\sum_{i=1}^{N} u_i, \tag{12}$$
$$\dot{x}_3 = x_4,$$
$$\dot{x}_4 = \frac{1}{J}\sum_{i=1}^{N}(T_m u_i - F_{xi}(x_1)) \cdot [(k-i)\Delta z + dz] \cdot \cos x_3,$$

where $x_1 = l$ is the displacement of the center of mass of the vessel along the x axis;
$x_2 = v$ is the rate of translational motion of the center of mass along the x axis;
$x_3 = \phi$ - the angle of rotation of the vessel;
$x_4 = \omega$ - vessel rotation speed;
$\boldsymbol{u} = (u_1 \quad u_2 \quad \dots \quad u_N)^T$ is the control vector, $u_i = T_i/T_m$, $i = \overline{1,N}$; T_i is the tension force of the cable of the i-th cart;
T_m - maximum allowable cable tension; $F_{xi}(l_i)$ - the load on the *i*-th drive, due to the forces affecting the cart at the point of the movement path l_i;
$m = m_c + N \cdot m_т$ is the mass of the vessel-carts object, m_c is the mass of the vessel, N is the number of carts, $m_т$ is the mass of the cart;
J is the moment of inertia of the vessel;
Δz is the distance between the centers of neighboring carts; dz is the distance from the rotation point (*RP*) (center of mass of the object) to the center of the k-th cart.

The output equations of the model are

$$y_j = x_1 - [(k-j)\Delta z + dz] \sin x_3,\ j = \overline{1,r}, \tag{13}$$

where r is the number of outputs needed to identify the motion parameters of a complex object.

As a result of linearization, a mathematical model was obtained in the states space in the vector-matrix form

$$\dot{\hat{\mathbf{x}}} = \mathrm{A}\hat{\mathbf{x}} + \mathrm{B}\hat{\mathbf{u}},$$
$$\vec{\mathbf{y}} = \mathbf{C} \cdot \vec{\mathbf{x}} \tag{14}$$

The matrices **A**, **B**, and **C** have a constant structure, but change depending on the operating conditions of the system and have the form

$$\mathbf{A} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ a_{21} & 0 & a_{23} & 0 \\ 0 & 0 & 0 & 1 \\ a_{41} & 0 & a_{43} & 0 \end{pmatrix}$$
$$\mathbf{B} = \begin{pmatrix} 0 & 0 & \cdots & 0 \\ K_1 & K_1 & \cdots & K_1 \\ 0 & 0 & \cdots & 0 \\ q_1 K_2 & q_2 K_2 & \cdots & q_N K_2 \end{pmatrix} \tag{15}$$
$$\mathbf{C} = \begin{pmatrix} 1 & 0 & q_1 & 0 \\ 1 & 0 & q_N & 0 \end{pmatrix}$$

The elements of the matrix **A** are defined as

$$\mathrm{a}_{21} = \mathrm{f}_{21}(\mathrm{x}_{1s}, \mathrm{x}_{3s}),\ \mathrm{a}_{23} = \mathrm{f}_{23}(\mathrm{x}_{1s}),\ \mathrm{a}_{41} = \mathrm{f}_{41}(\mathrm{x}_{1s}, \mathrm{x}_{3s}),\ \mathrm{a}_{43} = \mathrm{f}_{43}(\mathrm{x}_{1s}), \tag{16}$$

where $\mathrm{x}_{1s}, \mathrm{x}_{3s}$ are the elements of the stable state vector of the object $\mathrm{x}_s = (\mathrm{x}_{1s}, \dots, \mathrm{x}_{4s})^{\mathrm{T}}$ in a bounded neighborhood;
$\mathrm{K}_1 = -\mathrm{T}_m/\mathrm{m}$, $\mathrm{K}_2 = \mathrm{T}_m/\mathrm{J}$ are scale coefficients;
$\mathrm{q}_i = (\mathrm{k} - \mathrm{i})\Delta\mathrm{z} + \mathrm{dz}$, $\mathrm{i} = \overline{1,\mathrm{N}}$ is remoteness of the i-th force application point from the rotation point (the large-sized object mass center).

The elements of the matrix **C** correspond to the structure of the measurement system.

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The block diagram of the adaptive control system of complex object with observer and regulator, is shown in Figure 15.

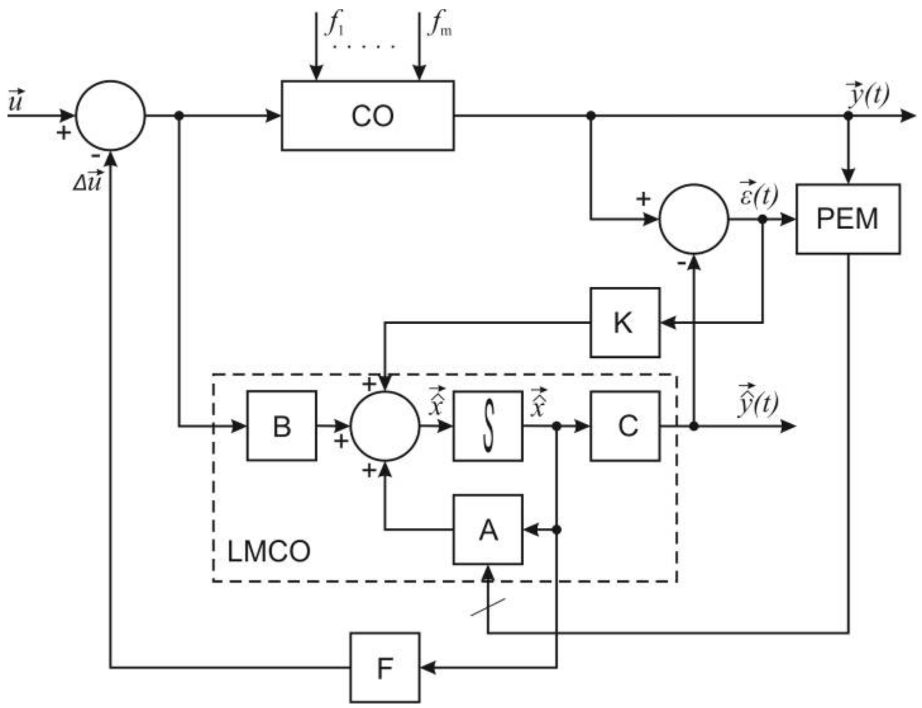

Figure 15. Block diagram of adaptive control system

The Parameter Estimation Module is marked at Figure 3 as "PEM", which implements the recurrent algorithm for matrix identification $\mathbf{A}$ of the linearized model control object (LMCO). The values changes of the matrix $\mathbf{A}$ components leads to the need to search a new values of observer matrix K and regulator coefficients F and, accordingly, to solve of Riccati equation [8].

The values of the components of the matrices $\mathbf{A}$, $\mathbf{B}$ and $\mathbf{C}$, can change during the process of moving the object, depending on the conditions of the system functioning, preserving its structure.

The values of the parameters of the matrices depending on the external and internal operating conditions of the system may change, which necessitates adjusting the values of the model parameters to maintain its adequacy. Thus, in connection with the changes in the parameters of the external environment on the trajectory of motion, it is necessary to periodically initiate a procedure for identifying model parameters.

To identify the parameters of the moving process model in real time, it is advisable to use recurrent procedures that make it possible to obtain an estimate of the model parameters when new dimensions arrive [9]. Recurrent evaluation procedures are determined by the dependence

$$\mathbf{P}[k+1] = \mathbf{P}[k] + \gamma[k+1] \cdot f(\mathbf{P}[k], \mathbf{y}[k+1], \mathbf{u}[k+1]) \qquad (17)$$

where $\mathbf{P}[k]$is the current estimate of the parameter; $\boldsymbol{\gamma}[k]$– the weight coefficient; fis some function that depends on the current value $\mathbf{P}[k]$ and determines the magnitude and direction of the next step; $\mathbf{y}[k+1]$ and $\mathbf{u}[k+1]$ are the output and input signals that follow after the current value.

The most famous recurrent procedures are the stochastic approximation method and the least squares method [10]. Since the accuracy of the stochastic approximation method can only be considered for $t \to \infty$, according to [9], therefore, it cannot be used when identifying model parameters for solving problems of controlling the large-sized object movement in real time.

Let us consider identification procedures using the methods of recurrent stochastic approximation and least squares to determine the parameters of the model for the process of moving a ship on a slipway, represented in the form (17).

When new measured information about the control object at discrete moments of time is received, it is expedient to use models in the state space of the form

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$$\mathbf{x}_{\mathrm{m}}[\mathrm{k}]=\mathbf{A}[\mathrm{k}-1]\cdot\mathbf{x}_{\mathrm{m}}[\mathrm{k}-1]+\mathbf{B}\cdot\mathbf{u}[\mathrm{k}-1]. \quad (18)$$

The adequacy of the object model is estimated on the basis of the values deviation analysis of the state variables obtained from the model $\mathbf{x}_{\mathrm{m}}[\mathrm{k}]$ and as a result of measurements $\mathbf{x}_{\mathrm{o}}[\mathrm{k}]$, that is by the value of the error

$$\mathbf{e}[\mathrm{k}]=\mathbf{x}_{\mathrm{o}}[\mathrm{k}]-\mathbf{x}_{\mathrm{m}}[\mathrm{k}]. \quad (19)$$

The algorithm for setting parameters has the form

$$\mathbf{A}[\mathrm{k}]=\mathbf{A}[\mathrm{k}-1]+\mathbf{\Gamma}[\mathrm{k}]\cdot\mathbf{e}[\mathrm{k}]\cdot\mathbf{x}_{\mathrm{m}}^{\mathrm{T}}[\mathrm{k}], \quad (20)$$

where $\mathbf{\Gamma}[\mathrm{k}]$ - is the matrix obtained on the basis of real values of the state vector measured over the entire observation interval $\mathrm{t}\in[\mathrm{t}_0,\mathrm{t}_{\mathrm{f}}]$, which can be determined recurrently by different ways.

In the case of the method of stochastic approximation as:

$$\mathbf{\Gamma}[\mathrm{k}]=\mathbf{\Gamma}[\mathrm{k}-1]-\mathbf{\Gamma}[\mathrm{k}-1]\cdot\mathbf{x}_{\mathrm{o}}[\mathrm{k}]\cdot\gamma[\mathrm{k}-1]\cdot\mathbf{x}_{\mathrm{o}}^{\mathrm{T}}[\mathrm{k}]\cdot\mathbf{\Gamma}[\mathrm{k}-1], \quad (21)$$

Where

$$\gamma[\mathrm{k}-1]=\left[1+\mathrm{x}_{\mathrm{o}}^{\mathrm{T}}[\mathrm{k}]\cdot\mathbf{\Gamma}[\mathrm{k}-1]\cdot\mathbf{x}_{\mathrm{o}}[\mathrm{k}]\right]^{-1} \quad (22)$$

In the case of the least squares method the matrix $\mathbf{\Gamma}[k]$ as:

$$\mathbf{\Gamma}[k]=\mathbf{I}_n\cdot\frac{\gamma}{k},\gamma>0, \quad (23)$$

To implement the both methods, it is necessary to specify the initial values of the state vector components of the model $\mathbf{x}_{\mathrm{m}}[0]=\mathbf{x}_{\mathrm{o}}[0]$, and also the matrix components initial values $\mathbf{A}[0]$, for the known dynamics of the control vectors $\mathrm{u}[\mathrm{k}]$and the state of the object $\mathbf{x}_{\mathrm{o}}[\mathrm{k}]$ for $\mathrm{k}=1,2,3,\ldots\mathrm{N}$. The initial values of the matrix $\mathbf{\Gamma}[0]$ are chosen as $\mathbf{\Gamma}[0]=\mathrm{I}\cdot(1/\alpha)$, where $\alpha$is a numerical coefficient whose value influence the convergence of the identification algorithm.

The end of the identification phase occurs with small deviations of the matrix $\mathbf{A}$ components values for all i and j, that is provided conditions

$$\left|\mathrm{a}_{\mathrm{ij}}[\mathrm{k}]-\mathrm{a}_{\mathrm{ij}}[\mathrm{k}-1]\right|<\delta \quad (24)$$

Let us consider identification procedures using the recurrent methods of stochastic approximation and least squares to determine the parameters of the model of the process of moving a ship on a slip.

In the process of calculations using the recurrent method of stochastic approximation, the best results were obtained using the algorithm tuning coefficient $\gamma=0{,}5$ and $\Delta t=1$, for the initial values of the model state vector $\boldsymbol{x}_m[0]=[0\quad 0{,}05\quad 0\quad 0]^T$. The initial and final values of the components of the matrix $\mathbf{A}$ are as follows

$$\boldsymbol{A}[0]=\begin{bmatrix}1&0&0&0\\0&1&0&0\\0&0&1&0\\0&0&0&1\end{bmatrix},\boldsymbol{A}[300]=\begin{bmatrix}1{,}061&-0{,}651&0{,}064&2{,}016\cdot10^{-3}\\0{,}012&0{,}356&-9{,}77\cdot10^{-4}&4{,}78\cdot10^{-4}\\0{,}087&-0{,}081&0{,}51&2{,}4\cdot10^{-4}\\-2{,}03\cdot10^{-5}&2{,}57\cdot10^{-4}&1{,}7\cdot10^{-6}&0{,}5\end{bmatrix}. \quad (25)$$

The change in the values of the matrix $\mathbf{A}$ components in the calculation process is shown in Figure 16. The structure of the resulting matrices (25) is significantly different from the structure of the matrix, resulting from the linearization of the nonlinear motion model. The end time of the identification phase using the recurrent stochastic approximation method was $t>350$s, which is unacceptably large when the vessel is moving, since the external conditions for the movement of a large object change with new objects and the definition of new matrix $\mathbf{A}$ values is required.

According to the theory [11], the accuracy of the stochastic approximation method can be considered only with $t\to\infty$ [6], therefore it is not advisable to use it when identifying model parameters to solve problems of controlling the movement of a large object in real time.

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It is advisable to analyze the effectiveness of more accurate identification methods in the control system, which allow you to maintain the structure of the matrixes of the linearized model of the process of moving the vessel on the slip, for example, the least squares method [12, 13].

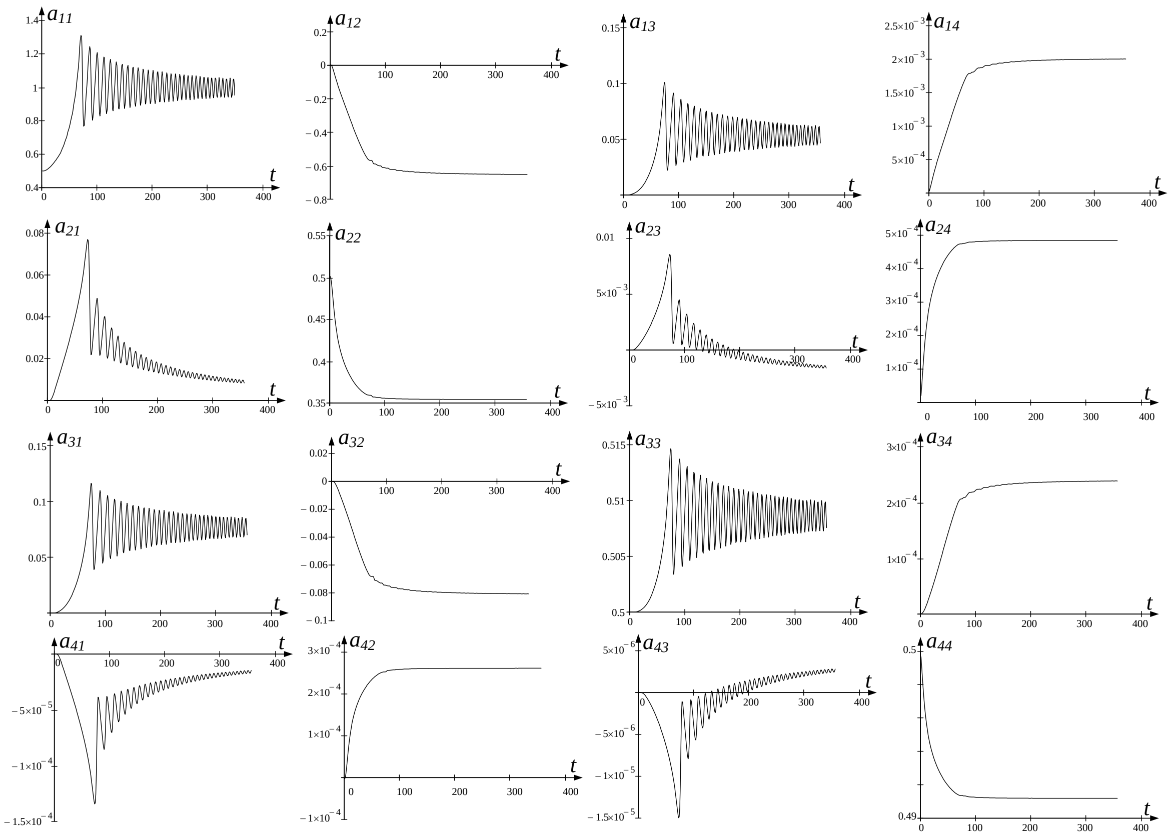

Figure 16. Dynamics of the adjustment of the values of the matrix **A** components obtained by using stochastic approximation method

Simulation of the identification process using the recurrent least squares method was carried out at the initial values of the state vector of the object and the initial values of the matrix A components in the form

$$\mathbf{x}_o[0] = \begin{bmatrix} 0 \\ 0{,}05 \\ 0 \\ 0 \end{bmatrix}, \qquad \mathbf{A}[0] = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & 0 & 1 & 0 \end{bmatrix}. \tag{26}$$

The change in the values of the matrix A components during the calculations is shown in Figure 17.

As a result of the calculations, a matrix **A** of the following form obtained

$$\mathbf{A}[350] = \begin{bmatrix} 0{,}98 & 1{,}02 & 0{,}14 & 5{,}63 \cdot 10^{-5} \\ \text{-}0{,}12 & \text{-}0{,}03 & 0{,}85 & \text{-}6{,}75 \cdot 10^{-5} \\ 0{,}15 & 2{,}95 \cdot 10^{-3} & 0{,}02 & 1 \\ \text{-}0{,}13 & \text{-}0{,}03 & 0{,}85 & \text{-}7{,}22 \cdot 10^{-5} \end{bmatrix}. \tag{27}$$

Taking into account the permissible error of 5%, the resulting matrix **A** can be written as

$$\mathbf{A}^* = \begin{bmatrix} 0{,}98 & 1 & 0{,}14 & 0 \\ \text{-}0{,}12 & 0 & 0{,}85 & 0 \\ 0{,}15 & 0 & 0 & 1 \\ \text{-}0{,}13 & 0 & 0{,}85 & 0 \end{bmatrix}. \tag{28}$$

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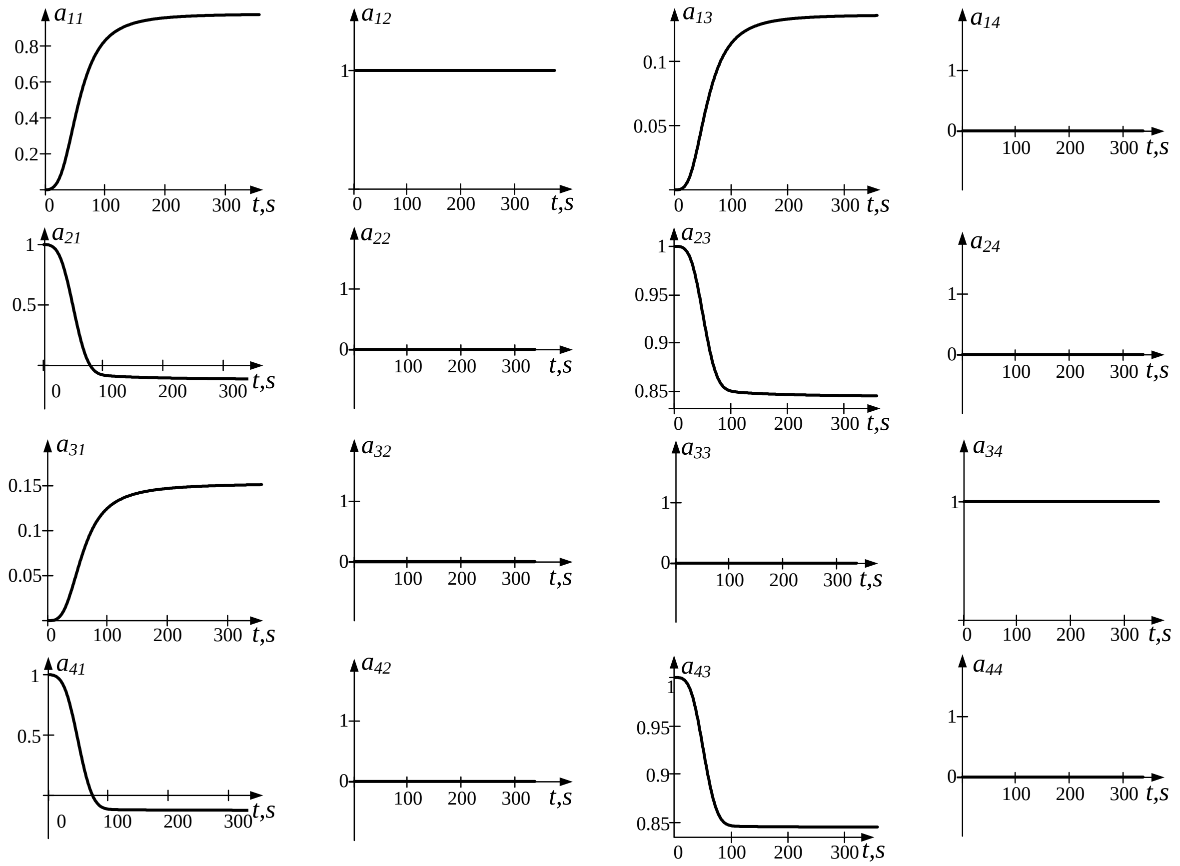

Figure 17. Dynamics of adjusting the values of matrix **A** components obtained by using least squares method

The best results are obtained if use the algorithm setting factor $\gamma = 150$ and $\Delta t = 1s$. The time of the end of the identification stage by the method of recurrent stochastic approximation was $t = 100s$, which is admissible, since only with $t > 300s$ the external conditions of motion of the large-sized object under consideration change and the determination of new matrix **A** values is required.

The graphs of the state vector components dynamics of the object (line 1) and the model (line 2) are shown in Figure 18.

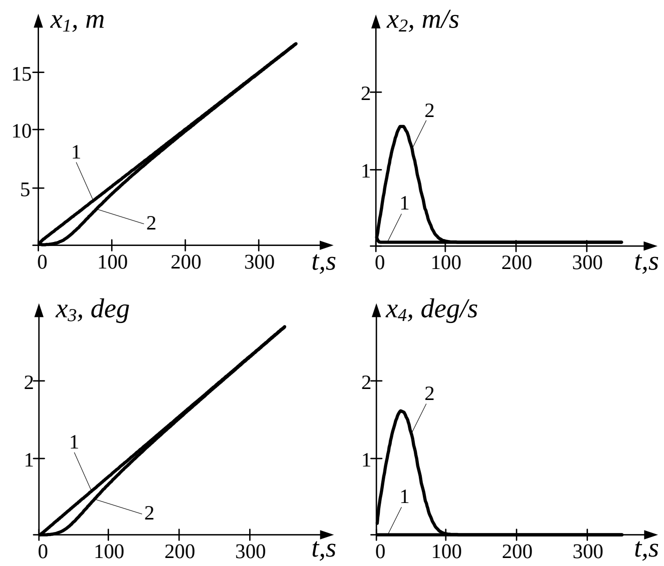

Figure 18. Graphs of dynamics of the states vector components

Graphs of the error dependence$\Delta x_i(t) = x_o(t) - x_m(t)$ are shown in Figure 19.

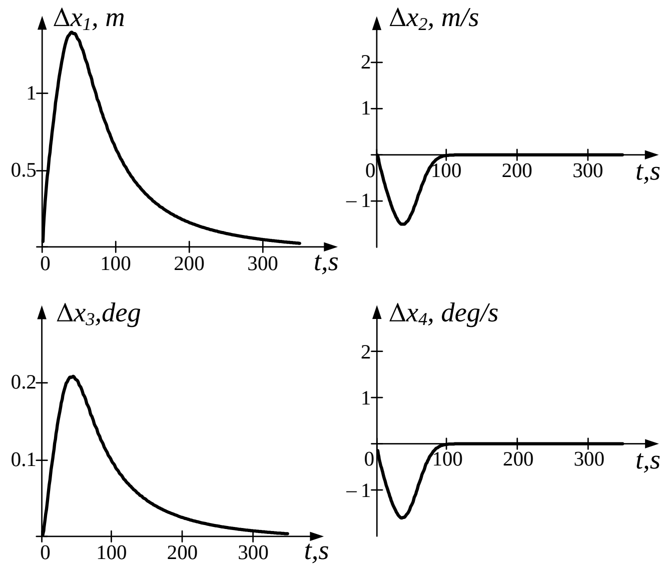

Figure 19. The graphs of the dynamics error

When changing the external conditions for a large-sized object moving, it is necessary to reactivate the identification process again. The activation condition of the identification phase is

$$|x_o(t) - x_m(t)| > \varepsilon. \quad (29)$$

When the external conditions for moving a large object change, it is necessary to re-activate the identification process. The condition for the activation phase identification

$$|y_o(t) - y_m(t)| > \varepsilon. \quad (30)$$

The study of the effectiveness of the procedure for identifying the parameters of a ship moving model on a slip by the recurrent method of stochastic approximation confirmed the adjustment problems of the algorithm associated with the choice of initial design values and weights that affect both its convergence and error, and also revealed that the allowable time allotted on the evaluation of model parameters. When identifying model parameters for adaptive real-time control of the process of moving a large object, it is advisable to use the least squares method [14].

3. Methods

Computerized control systems are often introduced to manage complex technical complexes. A characteristic feature of such systems is the presence of several levels of control. To control the slip-raising complex, it is advisable to use a two-level control system. The first (lower) level is used for direct control of individual slip actuators, while the second, the upper level of the system, serves to implement a specific strategy for launching or lifting a vessel [15].

Before the start of the salvaging works, an obligatory check of all units and mechanisms of the slip is performed. At the next stage, the operator sets the slip operation mode (descent / ascent) through the appropriate SCADA window and selects the type of vessel to be prepared for installation on the slip carts (if the required type of vessel is not in the database, the operator manually enters the information).

After entering the data, the system processes them using the available models and displays the corresponding recommendations on the display. After aiming and installation of the vessel on trucks and the beginning of their movement along the rail tracks, the control system continuously monitors the main parameters of the operating ship-lifting complex using the monitoring subsystem. The obtained data is used by local control systems and already together with the operating parameters of the local control unit (LCU) themselves go to the decision support system and the operator workspace, which serves the operator's workstation. The central control unit (CCU) determines the presence of deviations that are corrected by the LCU under the visual control of the operator. The

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launching / lifting of the vessel can be stopped at any time in the event of an emergency or as a result of a successful completion of work.

The algorithm of functioning of the computerized process control system for launching / lifting the vessel is shown in Figure 20.

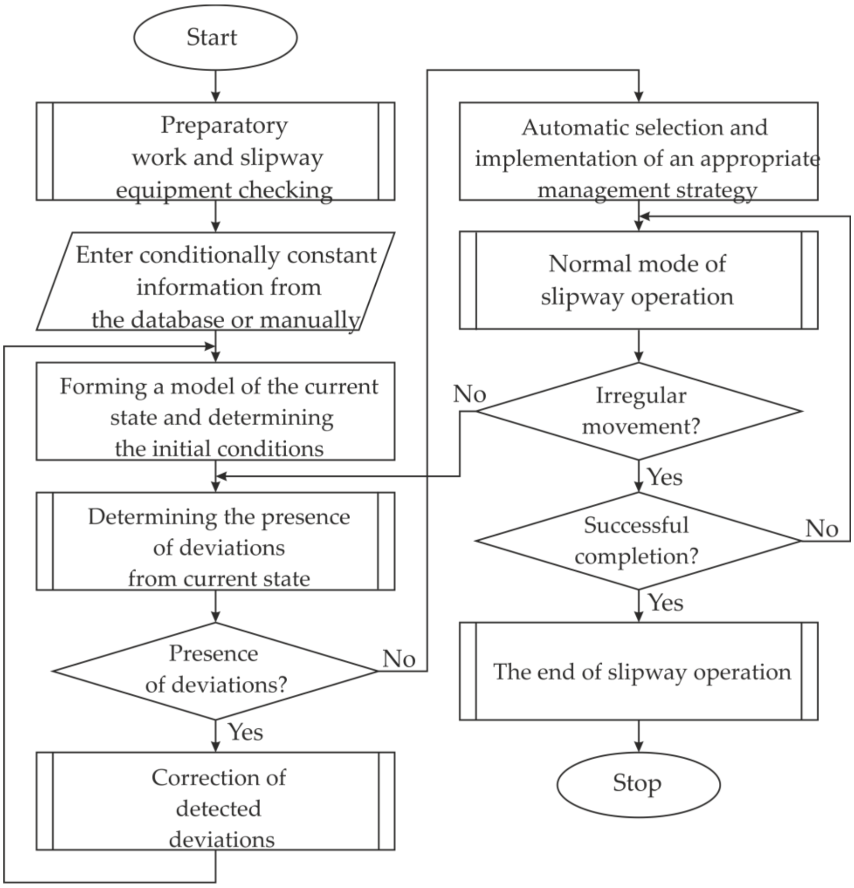

Figure 20. The algorithm of the control system work with the slip

The lower control level consists of the number of modules, the exact number of which depends on the number of slip carts. The slip trolley is driven by its electric drive, as a result, for the synthesis of control in the local system of the lower level, it is necessary to use information about the load (cable tension) and the operating parameters of the electric motor. Each of the lower-level control modules is a microprocessor system; however, due to the use of different electric motors on the slipways, they may have a different device.

The upper level of the control system is implemented using a controller, a set of appropriate input / output modules that form the central control unit (CCU), whose task is to coordinate the work of local lower level systems in order to stabilize the rotational movements of the vessel on the slip and maintain it uniform translational motion.

Effective operation of the central control unit is possible subject to the availability of an appropriate algorithm, a special database adequate to the mathematical model of the process of moving the vessel on the slip and timely information from the monitoring subsystem about the position of the trucks, their speed, the tension of the cable of each truck, the value of current in the electric motor circuits skewing of the vessel and from the control modules of the lower level.

To form the structure of information and measuring system, it is advisable to divide the factors that have a different disturbing effect on the work of a slipway, into four groups according to a functional feature, as shown in figure 21.

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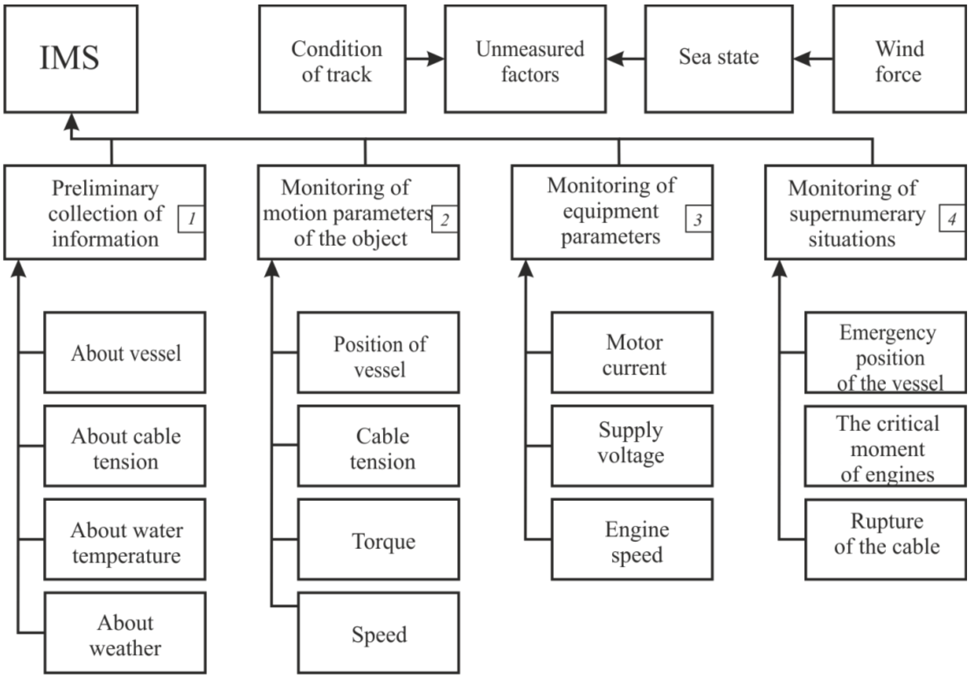

Figure 21. Analysis of factors affecting the work of slipway

Before starting the procedure of launching the vessel, it is required to collect preliminary information about the object and the external conditions.

Information on the type of vessel, its weight and size characteristics and the distribution of weight loads should be entered into the control system. The position of the carts should also be checked. Console ship-lifting complex should be provided with hardware and software automated workplace (AW). Continuous monitoring and control of the process parameters by the operator allows the implementation of SCADA-system. The developed models, theoretical and methodological approaches and recommendations can be used for the decision support system developed as part of the management system.

Decision Support Systems (DSS) includes the following components: a database (DB), a modeling subsystem, a problem solving subsystem, an interactive subsystem, a data transfer subsystem, and an information processing subsystem.

Data on the type of vessel, passport installation of the vessel on the slip carts, as well as, developed by the technical department of the enterprise, the scheme of lifting the vessel on the slip, can be entered into the DSS database. The database should store information on the largest possible number of vessels that can be serviced by the current slip, since the expected distribution of load between ship bogies plays an important role, and the coordinates of the center of gravity of vessels, due to their unequal design and architecture, are different. The availability and development of such a database allows not only to automate the slipway, but also to reduce the time of preparation for ship-lifting or launch operations.

Information on weather conditions and their impact on the work of the slip should also be stored in a database. The ship should be lowered under favorable weather conditions. However, due to the limitations imposed by the time of construction / repair and delivery of the vessel to the customer, as well as due to the reduction of equipment downtime, it can be problematic to delay ship-lifting work; therefore it is necessary to control the weather factors in order to be able to launch the vessel under satisfactory weather conditions.

The modeling subsystem should contain the developed models of the main units of the slip and model the operation of the ship-lifting complex based on the use of data entered by the operator or obtained from the database, helping the operator evaluate the progress of work and decide on the management of the ship-lifting complex using the task-solving subsystem. The data transfer subsystem connects the DSS with the information measuring subsystem and the lower level LCU. The interactive subsystem at the present stage is usually implemented by means of SCADA-system.

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The structure of the DSS is shown in Figure 22.

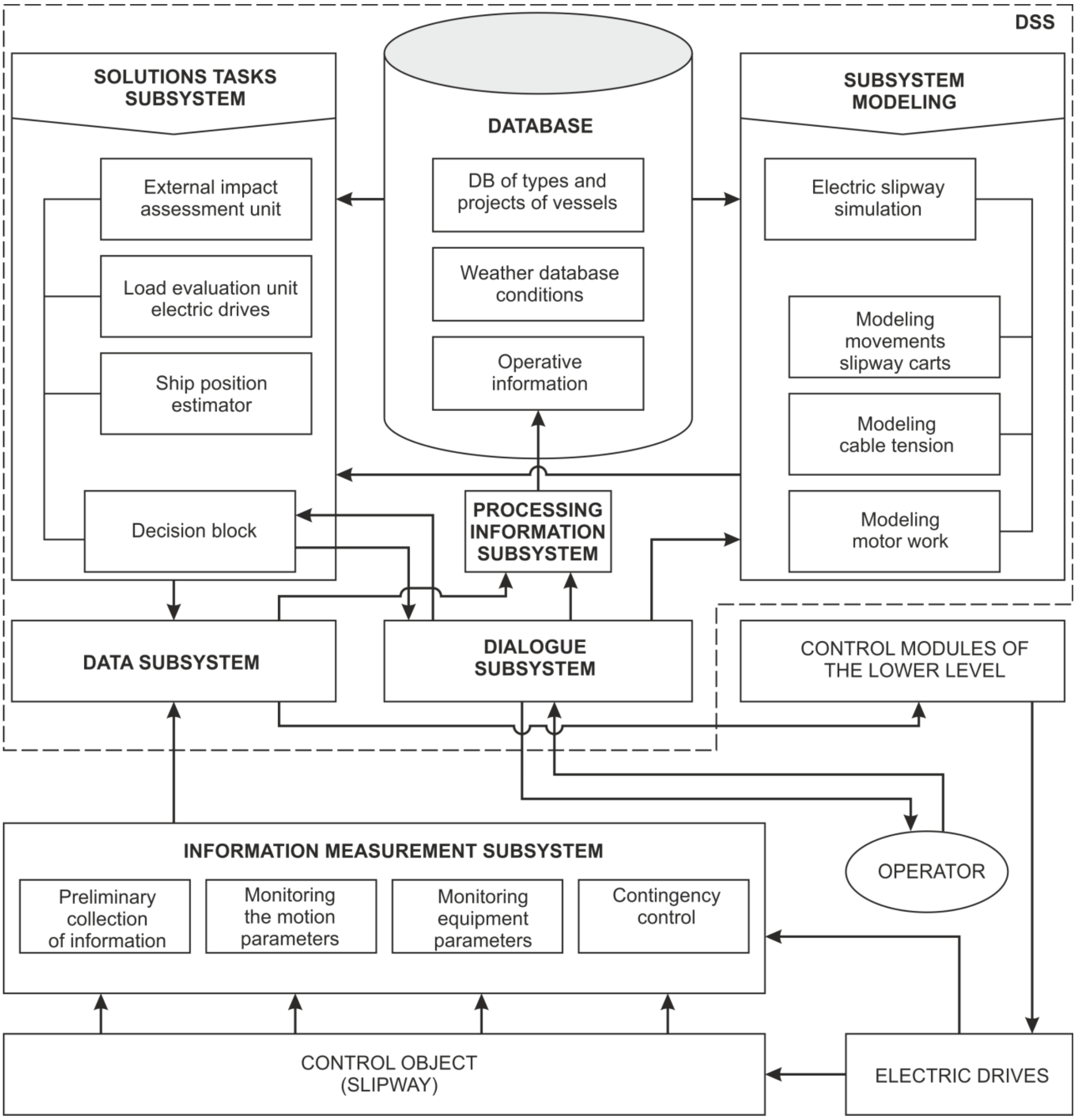

Figure 22. The structure of the DSS for the slip control system

The structural scheme of the computerized control system is presented in Figure 23. A set of sensors is installed on each electric drive of the slip cart: torque, cable tension and current, and for extreme drives, in addition, range-finder sensors. The information collected by the sensors enters of the preprocessing information units (IPPU). The sets of sensors and preprocessing blocks of information form the monitoring subsystem. From each IPPU, information is transmitted to the appropriate local control system, as well as to the central control unit. A separate LCU consists of an information processing unit (IPU), which serves to receive and process data from the monitoring subsystem, an engine control unit (ECU) used to control the electric motor, and a control module (CM) that controls the operation of the LCS, as well as the CCU, receiving commands from it and transmitting information about the functioning of the LCS. Together, local control systems form the lower level of control. The upper control level is represented by the central control unit and the automated workplace of the decision maker. The CCU is developed on the basis of one of the modern controllers that have proven themselves to be reliable and have qualified technical support, for example, on the basis of the Siemens SIMATIC S7-300 universal modular controller.

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The controller of the CCU, on the basis of the collected information from all IPPU and all LCS, performs basic calculations in the system, and then adjusts the work of the control modules. The results of the operation of the CCU are visualized on the display screen for the operator using a SCADA system. As a SCADA system for an automated workplace, it is possible, respectively, to use a multifunctional and universal SIMATIC WinCC system.

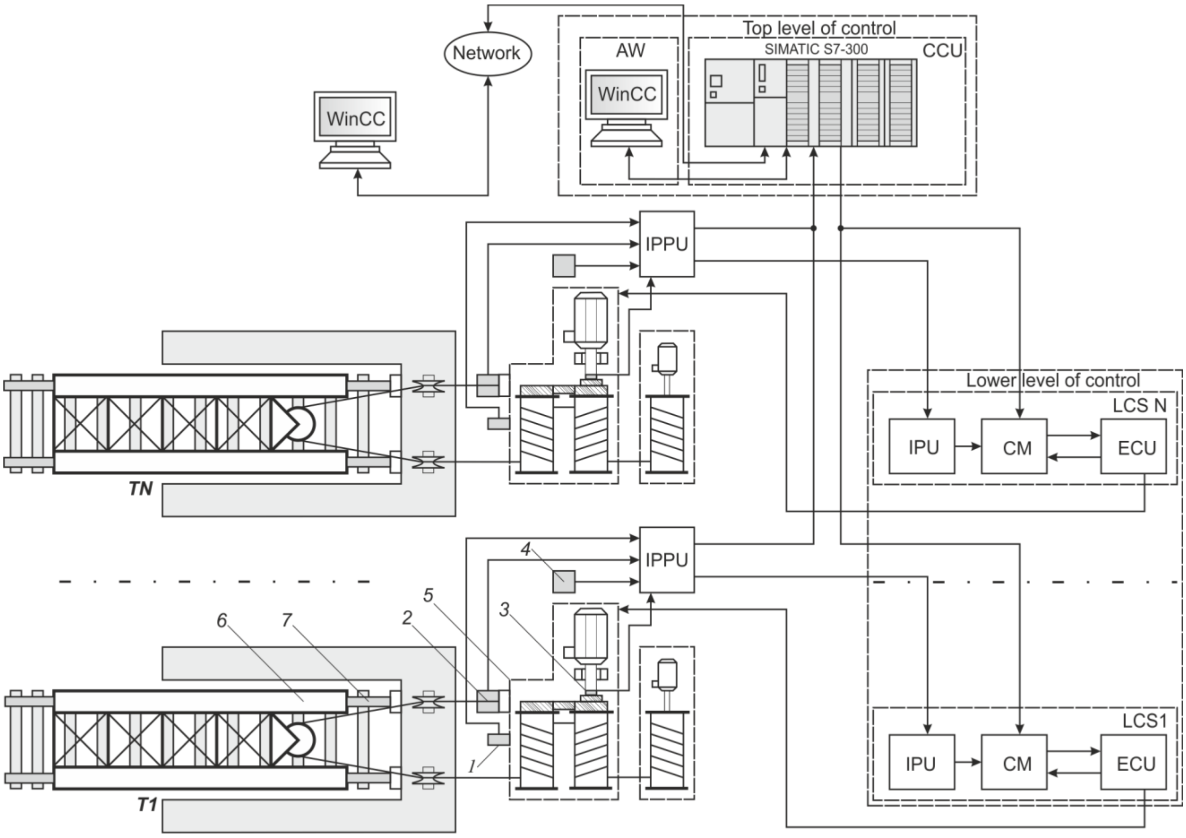

Figure 23. Block diagram of the computerized control system of the slip: 1 - measuring the distance to the vessel, 2 - sensors for measuring the tension force of the cable, 3 - measuring the moment on the shaft, 4 - sensors for measuring current, 5 - electric drives, 6 - ship-carrying carts, 7 - rail tracks

The considered computerized system will allow to increase the reliability of the slip operation and to ensure increased safety during the execution of lifting operations under uncertainty about external and internal factors of a random nature.

4. Conclusions

Analysis of the process of moving the ship on the slipway revealed the following problems: the need for coordinated management of a group of electric drives, the frequent occurrence of emergency situations, the impact of external and internal factors of a random nature. Ensuring safety and improving the reliability of the operation of the ship-lifting complex is possible through the introduction of an information management system and the use of adaptive management methods for the process of moving a ship on a slipway.

To analyze the operation of individual electric drives throughout the process of moving the vessel, a dynamic model of motor load based on the analysis of the forces acting on the ship's trolley was proposed, which allows estimating the cable tension at any point along the way depending on the design parameters of the system and external factors. To obtain an analytical description of the spatially changing system parameters, the apparatus of the theory of fuzzy sets is used.

A linearized model of the dynamics of the complex movement of the vessel in the process of moving on an inclined surface, taking into account the joint translational and rotational movements, as well as the structure of the multi-drive system, has been developed. The resulting model, which takes into account the influence of external factors and changes in the parameters of the ship-lifting complex, allows to ensure operational control and timely identifying the occurrence of critical situations during the operation of the ship-lifting complex.

The procedures for identifying the parameters of a ship moving model on a slipway by recurrent methods of stochastic approximation and least squares for use in an adaptive control system, that preserve the structure of the matrixes of the linearized model of the process of moving the ship on the slipway, are investigated.

The issues related to the implementation of the proposed models and methods for the operational control of the ship-lifting complex based on the use of modern microcontroller controls are considered.

The ways of further improvement of the decision support system in the automated system of operational management of the situation assessment module have been identified to ensure the coordinated operation of the multi-drive system, which allows for the maximum automation of the operational management process of the ship-lifting slipway-type complex.

Author Contributions: Hanna Rudakova and Oksana Polyvoda designed the model and the computational framework and analysed the data, and carried out the implementation. Anton Omelchuk performed the approbations. Oksana Polyvoda wrote the manuscript with input from all authors. Anton Omelchuk contributed to the final version of the manuscript. Hanna Rudakova supervised of the project.

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