Parametrization and identification of energy flows in the ship propulsion complex

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Abstract—**In the paper, using the predictive estimation method, based of the given initial and boundary conditions of the differential equations for the flows of propellers, an identification of energy flow markers characterizing the certain operating mode was made. The method of parameterization of the distribution of axial and tangential forces on the propeller flow lines of the ship power plants of the combined propulsion complex is determined. The corresponding characteristic markers depending on the intensity of degradation effects are given.**

Keywords—degradation effects; parameterization; identification; markers; propulsion

I. INTRODUCTION

Recently, with the development of technology and increasing requirements for the accuracy of the regime of dynamic positioning (DP) of vessels, as well as to simplify maneuvers in the limited space of work, ships are increasingly equipped with azimuthal thrusters (AZTHR). They can be installed as an additional, as well as the main driving units [1]. The main task is to ensure the stability of the vessel and controllability in the wide range of these types of vessels.

However, during the operation and maintenance of AZTHR there are situations in which their safe and efficient work is reduced [2]. To maintain an object at the position of the AZTHR sends the stream of water under the bottom of the vessel and in this case, there is the probability of occurrence Koanda effect, in which the flow "stick" to the bottom of the ship [3]. Due to the feature of the design of the AZTHR, that is, its location below the bottom of the vessel below the waterline, complicated access to the diagnosis. Unfortunately, it is not possible to predict and calculate the process with the detailing of all parameters, as many factors influence the appearance of the Koanda effect:

- reduction of propeller thrust and torque due to the flow of water perpendicular to the axis of the propeller, caused by the flow of flows from other engines with force in the direction of the flow due to the deviation of the screw flow. It is often referred to as the cross-combination of resistance;
- the presence of cavitation for heavy loads on the screws, which leads to a decrease in pressure on the propeller blade;
- sudden drop in traction and torque with the effect of hysteresis due to the large amplitudes of the vessel perpendicular to the surface of the water;
- simultaneous reduction of traction and change of direction of traction due to the interaction of the flow from the thrusters with the case;
- the loss of the stopper of the propulsion and reduction of traction caused by the influence of the propulsion flow from one engine to the neighboring engines;
- limitation of the increase of the torque by induction of the engine to prevent damage to the mechanical part of the electric drive;
- limitation of the maximum power of the thrusters, which is taken into account in determining the reloading capacity of the electric motor and the frequency converters (FC);
- absence of the control strategy of the FC, based on invertible regulators, which would ensure the transition of thrusters working on the hyperbolic of constant power to the mode of regulation of the torque or speed of rotation.

The identified problems and separate tasks in the direction of increasing the energy efficiency of ship power plants (SPP) of combined propulsion complexes (CPCs) have some local unsystematic solutions, which made it possible to establish the need for the more detailed study of exactly the energy flows at all intersections from medium-rotating diesel generators to propulsion engines, taking into account not only the environment, but also situational factors and changes in operating modes.

Solving the problem of improving the functioning of the DP with the provision of the necessary, technologically-determined, accuracy of positioning taking into account the effects of external perturbations on the high seas is such that it should increase the energy efficiency of the SPP CPCs and affecting the quality of the forecast for the change in energy efficiency factors.

II. Purpose of work

Design of the method of identification of the dependence of the characteristics of the SPP for CPCs on the degradation effects occurring on the lines of the propeller streams during the change of operating mode or environmental parameters.

III. Contents and results of the research

All motors installed on vehicles operating in DP mode can be stabilized with torque (thrust) or rotational speed regulation, but each type of trimming device thrusters has its own characteristics and some important parameters will have somewhat different meanings for different types of thrusters. However, the same for all types of thrusters is that the calculation of hydrodynamic processes on the lines of screws of the thrusters SPP of the CPC is possible using the Navier-Stokes equation [4]:

$$\frac{\partial \vec{\upsilon}}{\partial t} = -(\vec{\upsilon}\nabla)\vec{\upsilon} + v_w \Delta \vec{\upsilon} - \frac{1}{\rho}\nabla P_v + \vec{f}_m ;$$

$$\nabla \cdot \vec{\upsilon} = 0 , \qquad (1)$$

where: ∇ – nabla operator;
Δ – Laplace vector operator;
t – time, [s];
v_w – coefficient of kinematic viscosity, $\times 10^{-6}$ [m^2/s];
ρ – the density of the environment, [kg/m^3];
P_v – flow pressure, [Pa];
$\vec{\upsilon} = (\upsilon^1, \ ..., \upsilon^n)$ – vector velocity field;
$\vec{f}_m$ – vector field of mass forces.

It can be assumed that, for turbulent water flows from the propellers, thruster propellers motor SPP CPCs is generally based on the Navier-Stokes equation (1), which is valid both in laminar and in turbulent mode of fluid flow; but using this Navier-Stokes equation for turbulent motion is practically impossible. In it, the input instantaneous values of the velocity and pressure of the flow are pulsing values, so for the turbulent regime the task of finding averaged in time velocities and pressures. To do this, the Reynolds equations are derived based on the Navier-Stokes equation, all members of which undergo averaging operation in time [5].

In order to obtain the results that are adequate to the real mode, depending on certain identification parameters and situational factors, the dependence on the level of flows from the propellers must pass the averaging operations, based on the assumption of the existence of any such turbulent motion of such an interval of averaging made on it, give the value of unchanged at repeated averaging [6].

The pulsating components of the variables are characterized by frequency and amplitude, and the average pulsation amplitudes are characterized by corresponding coefficients of pulsations [7].

Calculation of the existing traction forces on the screws is the complicated condition, since there is no priority flow direction in most of the region, so the iterative procedure for solving the nonlinear equation (1) is unstable for steady regimes. Therefore, to solve this problem, the coefficients of the K_T screws and the coefficients of the K_F screws moment for the current velocity of the vessel υ_i will be determined provided that they are predetermined by the corresponding coefficients for the absolute velocity of the vessel and the velocity of the inflow of water, which must be formalized according to the equations of similarity for certain numbers Reynolds and Froude and the associated flow coefficient w_s: $\upsilon_a = (1 - w_s)\upsilon_s$, where, as the rule, $0 < w_s < 0.4$:

$$F_p = \frac{\upsilon_i}{n \cdot D_p}, \qquad (2)$$

where: n – propeller rotation speed, rev/s;
D_p – diameter of the propeller, m.

The registration of the combination of efforts on the shaft lines in the SPP of the CPCs gives reason to assert that the sensors, as some generalized elements, should have more significant ranges of measurement of input quantities. Therefore, the main purpose of constructing or choosing the mathematical model of the sensor is to find such analytical descriptions of physical processes that occur in the process of converting energy into them, which would allow us to use the types of mechanical influences that are most commonly encountered [8].

The critical tasks for determining the coefficients of proportionality for disturbing forces, as well as situational factors and identification parameters of operational regimes, will be formulated and solved analytically. Simple transcendental equations for determining the length of the contact area, the voltage, the electric and magnetic fields, the intensity coefficients and the length of the contact area will be determined for different load cases, with the observation of the influence of the factors of electric fields on the length of the contact area. The results to be obtained will have the potential application in the development of multilayer electro-elastic structures and devices for recording disturbing effects at the intersections of energy flows in the SPP of the CPCs, which are under the influence of non-deterministic loads in different operating modes.

The general solution for equation (2) will be to find the coefficients of the polynomial for the steady state of the perturbing forces determined by the flow quality according to equation (1) to the certain sensor (sensor), provided that the operational mode of the SPP of the CPC remains unchanged for the duration of the calculation time [9]:

$$\begin{cases} \overline{\boldsymbol{U}}_S(\boldsymbol{Z}) = \overline{\boldsymbol{I}}_S(t)\cdot \boldsymbol{Z}_{SE} + t_{EM}\cdot \bar{\upsilon}_S(t), \\ \overline{\boldsymbol{F}}_S(\boldsymbol{Z}) = \overline{\boldsymbol{I}}_S(t)\cdot t_{ME} + \boldsymbol{Z}_{SM}\cdot \bar{\upsilon}_S(t), \\ (m_{cS}+m_{ncS})\cdot \dfrac{d\,\bar{\upsilon}_S(t)}{dt} + \mu_S \bar{\upsilon}_S(t) + \mu_R \int_{\varepsilon_0}^{\varepsilon} \bar{\upsilon}_S(t)dt = \overline{\boldsymbol{F}}_S(\boldsymbol{Z}), \end{cases} \quad (3)$$

where: $\boldsymbol{F}_S(\boldsymbol{Z})$ = $(\boldsymbol{F}_{S1}(\boldsymbol{Z}^1)$, $\boldsymbol{F}_{S2}(\boldsymbol{Z}^2)$, $\boldsymbol{F}_{S3}(\boldsymbol{Z}^3)$, $\boldsymbol{F}_{S4}(\boldsymbol{Z}^4)$, …, $\boldsymbol{F}_{Si}(\boldsymbol{Z}^m)^{Tmatrix(i)}$;

$\boldsymbol{Z}^m = \boldsymbol{R}^m + p_{ij}\boldsymbol{L}^m$ — the complex impedance is determined by the matrices of the active and inductive components of the circuit for replacing the complex load;

$T_{matrix(i)}$ — matrix of the configuration parameters of the trimming devices, where (i = 0...k) is the number of the corresponding configuration;

- $m = \gamma_S \times S_S \times d_S / g$ [kg] – mass sensor;
- $\bar{\upsilon}_S(t)$ – the velocity with which the system fluctuates in the zone of application of force $F_S(t)$, [m/s];
- $\gamma_S = 7\cdot 10^4$ [H/m^3] – specific weight;
- S_S – cross-sectional area, [m^2];
- d_S [m] – thickness of the contact layer;
- g – gravity [m/s^2] or acceleration of free fall;
- $\mu_S \times 10^{-2}$[kg/m×s] – index of internal friction of sensor material;
- μ_R – index of viscosity of the medium, or index of friction, $\times 10^{-2}$[kg/m×s];
- ε – dialectical permeability of the environment, [Fa/m];
- ε_0 – electrical constant, 8,8×10^{-12} [Fa/m];
- $F_S(t)$ – force acting on the contact area, [H].

The corresponding force of the propeller of the thruster's propeller will be calculated based on the values of two radii (the radius along the edge of the screw R_p and the radius of the intersection of the spade of the propeller r_p) and the thickness of the spade of the screw b_p, which can be uniquely determined as the axial characteristics of the blades from their intersection. Axial and tangential forces in accordance with the axial forces F_x, F_y, F_z as the scaled algebraic distribution, which integrates to the required traction, and tangential correlates, are determined by the stop and torque of the screw, which is simulated, based on the following considerations: the properties propellers like stepping ratio screw p_D (H_P/D_p) and determined the current value of the propeller stops T_d.

In this case, the coefficients taking into account the reduction in traction can be determined by replacing the resistance with the corresponding effort for all three (surges, sway, yaw) [10]:

$$C_{F_{lh}} = \frac{F_l(\upsilon_a,n) - T_{ux}(\upsilon_a,n) - F_l(\upsilon_a,0)}{T_u(\upsilon_a,n)}, \quad (4)$$

$$C_{F_{bh}} = \frac{F_b(\upsilon_a,n) - T_{uy}(\upsilon_a,n) - F_b(\upsilon_a,0)}{T_u(\upsilon_a,n)}, \quad (5)$$

$$C_{F_{zh}} = \frac{F_z(\upsilon_a,n) - T_{uy}(\upsilon_a,n)X_p - T_{ux}(\upsilon_a,n)Y_p - F_z(\upsilon_a,0)}{T_{uy}(\upsilon_a,n)X_p - T_{ux}(\upsilon_a,n)Y_p}, \quad (6)$$

where: $F_l(\upsilon_a,n)$, $F_b(\upsilon_a,n)$ i $F_z(\upsilon_a,n)$ – general forces (H), are acting on the vessel, provided that there are no other external perturbations at the flow rate of water υ_a (m/s) and the corresponding number of turns of the fixed propeller pitch (FPP), n (rpm);

$F_l(\upsilon_a,0)$, $F_b(\upsilon_a,0)$ i $F_z(\upsilon_a,0)$ – the corresponding forces (H) in the case of the fixed propeller (for example, the flow);

$T_{uy}(\upsilon_a,n)$ i $T_{ux}(\upsilon_a,n)$ – traction (H) on the corresponding axis relative to the plane of motion.

On the other hand, for the promising concepts of CPP CPCs with hybrid ship propulsion systems with counter-rotating propellers (CRP) operating in DP mode, dominated by gravitational forces, and the law of similarity of Froude is in force, for which the equality of numbers for model and nature is required, that is, $F_{rM} = F_{rN}$, the similarity criteria must be expressed through the values characteristic of the given mode [11].

All relations taken into account in (4), (5), (6) as models and constraints are given in the class of integro-differential equations and inequalities

For the research object of the SPP of the CPCs, as the class of complex technological system (CTS), the number of such ratios is usually large, and vector variables have the large dimension, which causes the high complexity of tasks. Solving similar tasks in power distribution systems of SPP CPCs that have the traditional centralized structural organization with compliance with the requirements of efficiency and accuracy of the definition of management decisions is often difficult or even impossible.

In these cases, decomposition methods that are implemented in decentralized control systems (CSs) with the hierarchical structure can be used. Methods of decomposition involve the reduction of the initial complex task to the set of simpler jointly solved tasks. In the simplest case, it is the local task of controlling the individual subsystems, selected in the CTS, which are solved at the lower level, and the global task of coordination, which is solved at the upper level.

The joint solution of local and coordination tasks is carried out within the framework of an interactive level data exchange procedure, in which the local tasks take into account the set values of the coordinating parameters that are selected in the course of the task of coordination. The solution of the task of coordination is the significance of its variables, in which the solution of local problems predetermine the solution of the original problem to change the operational regime of the SPP CPCs in general.

The two-level solution procedure can also be used for local tasks. As the result, the general procedure for solving the initial problem of the research of the SPP CPCs is realized by the creation of the CSs, which becomes the multilevel. Methods of decomposition are developed mainly for static research tasks, whereas for dynamic tasks they have been processed to the much lesser extent.

The decomposition method for the dynamic control tasks of the CTS based on the construction of the original problem into the sequence of static tasks that takes into account the prevailing in the SPP of the CPC until the moment of making control decisions is applied. As the result, the task is decomposed according to the operating mode. In this case, the considered modes may correspond to simplified, sometimes significant, static.

When the body of the vessel is flowing with water as the characteristic linear size choose the length of the vessel between the perpendiculars along the waterline and the draft in the direction of flow, and as the characteristic velocity – the rate of flow flowing.

That is, all previous calculations torque acting on the propeller shafts lines thruster's SPP CPCs will do as follows:

$$\frac{F_x(\hat{r}), F_y(\hat{r})}{F} = \left(\frac{a+\hat{r}}{a+1}\right)^m \left(\frac{b+1-\hat{r}}{b+1}\right)^n, \qquad (7)$$

where $\hat{r} = \dfrac{r - r_p}{R_p - r_p}, \quad (r_p \le r \le R_p),$

$$T_p = \int_{-\pi}^{\pi} \int_{0}^{1} F_x(\hat{r}), F_y(\hat{r}) d\hat{r} d\theta. \qquad (8)$$

The distribution of axial forces is parameterized according to the values of the identification coefficients *a*, *b*, *m*, *n*, or so-called characteristic flow energy markers (situational factors) characterize the certain operating mode. The non-zero distribution of the axial force component can be set across the entire range ($r_p \le r \le R_p$) by carefully selecting parameters *a* and *b*. The value of the integral components corresponds to the chosen direction of the propeller, T_p.

In turn, the tangential components of emphasis and moments are calculated as follows

$$\frac{F_\theta}{F_x, F_y}(\hat{r}) = \frac{H_P / D_p \times R_p}{\pi \times r}, \qquad (9)$$

$$M_p = \int_{-\pi}^{\pi} \int_{r_p}^{R_p} r \times F_\theta(\hat{r}) d\hat{r} d\theta.$$

In Fig. 1, 2 shows the comparative results of two set of parameters for the power components of the radial distribution of the thrust of the thrusters in the moving coordinate system. The values of the components of forces on the graphs are not presented, since the distribution is scaled for given traction and torque.

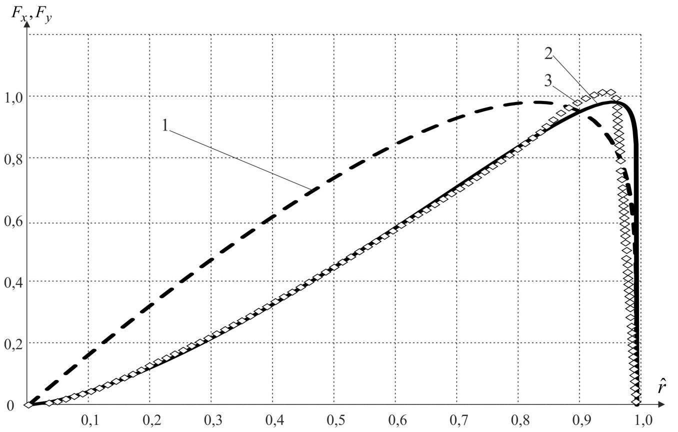

Fig. 1. Components of axial forces proportional to the radius of the envelope blades of the propeller: 1 – the initial parameters in accordance with the boundary conditions of the operating regime and situational factors; 2 – selected parameters; 3 – according to passport values

The initial choice of the parameters of the axial forces of the model occurred according to equation (3), and then, taking into account the data obtained in (7), (8) for the models of the thrusters, these initial assumptions were improved (6). Analyzing results for open water, the physical model of thrusters at 100% speed for maximum thrust, the following set of parameters was established:

$$(a, b, n, m)^* = (0;\ 0;\ 1{,}47;\ 0{,}07). \qquad (10)$$

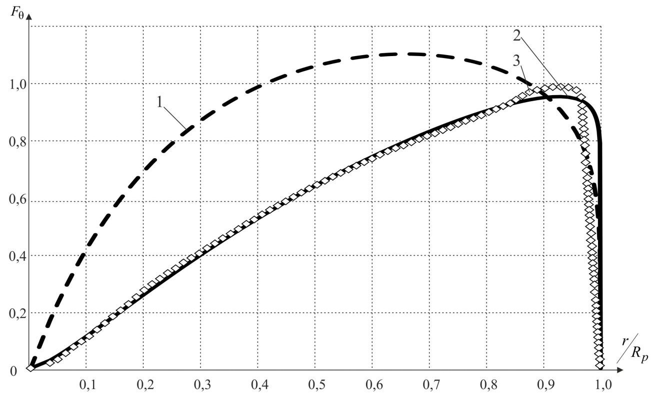

Fig. 2. Components of tangential forces proportional to the radius of the propeller: 1 – the initial parameters in accordance with the boundary conditions of the operating regime and situational factors; 2 – selected parameters; 3 – according to passport values.

With certain statistical properties of the perturbations applied to the SPP of the CPC, we will estimate the coefficients of the model by experimental data using the regression analysis procedure. Given the experimental data in the *N* points of the domain of the determination of independent variables, and having the matrix of observations *X* and the output vector *Y*, the model of the SPP of the CPC is constructed in the form of the regression equation:

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ .. & .. & .. & .. \\ x_{N1} & x_{N2} & \cdots & x_{Nn} \end{bmatrix}; \quad Y = \begin{bmatrix} y_1 \\ y_2 \\ . \\ . \\ . \\ y_N \end{bmatrix}, \tag{11}$$

$$\varphi(x_1, x_2, ..., x_n) = \beta_0 + \sum_{(i=1)}^{n} \beta_i x_i + \sum_{(i,j=1)}^{n} \beta_{ij} x_i x_j + ..., \tag{12}$$

where β_0, β_1, β_{ij} are sample estimates of the coefficients of the equation (7); φ – estimation of the mathematical expectation of the random variable.

To calculate the coefficients of the regression equation, we use the least squares method. In this case, the criterion for approaching the model to the investigated function is the sum of the squared deviations of the output value, calculated using the constructed model from the actual values obtained in the experiment. The best approximation will be such an equation, the coefficients of which are determined from the minimum condition of this amount,

$$Y = min \sum_{k=1}^{N} \left(y_k - \sum_{i=0}^{t} b_i x_{ki} \right)^2 . \tag{13}$$

For calculate the coefficients of the regression equation that provide the minimum value of the criterion (13), it is necessary to solve the system of equations obtained by zeroing time derivatives from the residual sum of unknown variables β_0, β_1, β_{ij}:

$$\frac{\partial \sum_{k=1}^{N} \left(y_k - \sum_{i=0}^{t} b_i x_{ki} \right)^2}{\partial b_i} = 0; i = 1, 2, \ldots, t. \tag{14}$$

The equations thus obtained are close to the normal equations, which are appropriate to be solved by representing them in the matrix form:

$$(X^T X)B = X^T Y, \tag{15}$$

where X – matrix of observations of independent variables; X^T – transposed matrix X; Y – vector-column of observations of the dependent variable; B – vector-column of coefficients of the regression equation.

The coefficients of regression model B and its calculated values of y are random variables, but in order to estimate the model's errors and its suitability for describing the studied SPPs and CPCs, it is necessary to make so many statistical treatments of the results of the experiment as the identification procedures were carried out.

Therefore, for the system of random variables b_0, b_1, ..., b_t with the theoretical mean values β_0, β_1, ..., β_t we compile the matrix of other central moments defining all the statistical properties of the coefficients B, and hence the regression equation $\hat{Y} = XB$. We obtain the matrix of dispersion-covariations M^{-1}, the main diagonal of which are dispersion estimates, while the remaining places occupy estimates for the variations of the coefficients of the regression equation

$$M^{-1} = \begin{bmatrix} s^2\{b_0\} & cov\{b_0 b_1\} & \cdots & cov\{b_0 b_m\} \\ cov\{b_1 b_0\} & s^2\{b_1\} & \cdots & cov\{b_1 b_m\} \\ .. & .. & .. & .. \\ cov\{b_m b_0\} & cov\{b_m b_1\} & \cdots & s^2\{b_m\} \end{bmatrix}. \tag{16}$$

From here we obtain the relation for the estimates of variances and covariances of the coefficients of the regression equation $s^2\{b_i\}=c_{ij}^2\{y\}$; $cov\{b_i b_j\}=c_{ij} s^2\{y\}$.

The variance of the reproducibility $s_2\{y\}$ is determined by the formula

$$s^2\{y\} = \frac{\sum_{k=1}^{N} \sum_{q=1}^{m_k} (y_{kq} - \bar{y}_k)^2}{\sum_{k=1}^{N} (m_k - 1)}, \tag{17}$$

where $\bar{y}_k$ is the average value of y_k, is determined from the data of m_k of repetitive experiments. The magnitude $f_y = \sum_{k=1}^{N} (m_k - 1)$ is the number of degrees of freedom of dispersion of the reproducibility of the entire experiment. The estimation of the variance of the coefficients of the regression equation allows us to determine the significance of the coefficients, that is, to clarify the structure of the model SPP CPC.

The ability to change the settings of the thrusters, in particular: the values of step ratios, the stacking and alignment factors of the axes of the main and auxiliary propellers, for the particular vessel significantly expanded the use of the approach in terms of acceleration of convergence of the synthesized DMI-models of vessels, and for given speeds of rotation of propellers, traction, torque and stepping ratio allowed to establish that the traction factor (thrust) increases with the change in the relative position of the propulsion system with respect to each other and the diameter of the vessel.

Experimental investigations for the applied thrusters configurations were carried out on the physical model of the CPC. In the framework of the solution of the fifth main task, which became an inalienable prerequisite for solving other main problems, the physical model of the multifunctional CPC with the variable structure which, in synergy with the solution of the fourth main task, allowed multiple analysis of the structures of the SPP and the CPC with minimal output data, namely: 1) the ability to verify the settings of the thrusters, in particular the values of the step ratios, the coefficient emphasis and arrangement of the axes of main and auxiliary propellers; 2) synthesis of DMI-models of ships for given speeds of rotation of propellers, traction, torque and stepping ratio; 3) calculation of the traction (thrust) coefficients with the change of the mutual position of the thrusters relative to each other and the plane of symmetry of the vessels; 4) correlation of the coefficients of emphasis to power factors and step coefficients of propellers. The developed physical model allows us to investigate the qualitative and reliable indices of the SPP of the CPC, their aggregates at the stages of designing of the constructions and technologies, production and operation, to establish the regularities of the change of the parameters of the technical condition during the operation, to introduce methods and means of diagnosing and forecasting the technical state of the SPP of the CPC, to provide high efficiency their use and reliability of work.

In the section of the methods of computational hydrodynamics, the principles of the formalization of physical models of azimuth handlers are developed in terms of tracking the degradation effects on the lines of the propeller flows.

Scientific and applied results, conclusions and recommendations are as follows:

- the geometry of the physical model of the trimming device with two degrees of freedom is calculated and the necessary physical conditions of its realization are indicated;
- formalized geometric parameters of the model, given the initial and boundary conditions of the differential equations describing the behavior of the ropes of the propellers in the recirculation zones and the coefficients taking into account the presence of degradation effects;
- in accordance with the given algorithm, the solutions of the basic equations are obtained from the point of view of the fundamental physical parameters, as well as the ordered results of the solutions.

IV. Conclusions and Recommendations

As the result of the research of means of diagnostics and prediction of the technical state of the SPP of the CPCs, the method of computational hydrodynamics was improved through the use of piezoelectric sensors on the lines of shaft lines of azimuthal thrusters, which allowed to trace the degradation effects from the interaction of the propeller fluxes between themselves and the body of the CPCs.

Further development of the theoretical positions of forming the equations of energy processes in the CPC during the analysis of the behavior of multiphase non-stationary non-stationary flows of propellers by high order methods using the special laws of distribution of the required intensities of the most influential degradation effects: the method of calculating power flows from azimuthal propulsion in the form of the drive disk and identification turbulent regions with relative coefficients of vortex viscosity μ_t/μ_w.

The specialized method for calculating the components of x-velocities at the intersection of the flow of the propellers of the azimuthal thrusters along the axis of rotation with the dimensions in units of the diameter of the propeller D_p is constructed on the basis of the realization of the surface-oriented averaging method of the Reynolds Navier-Stokes equation for mass transfer at the boundary of the phase separation. In this case, we managed to avoid the number of difficulties related to the nonlinearity of the method and to take into account the actual form of azimuthal thrusters without any approximations.

Also, due to the possibility of increasing the number of cross sections of measurements, it is possible to fully analyze the effectiveness of the proposed methods of combating the above degradation effects.

The ratio of the coefficients of the thrust of the thrusters of the CPC is better correlated to the power factors than to the step coefficient of the propellers, which gives grounds to consider the increase of the energy efficiency of the SPP of the CPC in operational modes and gives the opportunity to add the obtained results to the database of decision support systems (DSS) to provide developers and researchers the necessary information to create new concepts of SPP CPC or to modify existing ones.

Determination of the values of the thrust applied to the vessel and the formation of the thrusters configuration matrix with the distance from the point of application of the thrust of the separate thrusters to the projection of the force vector τ_T on the plane of the vessel is possible on the basis of studying the internal properties of the components of the SPP of the CPC, operating in the dynamic positioning mode, from identification of relevant identification factors.

Getting dependencies of corrective factors affecting the components of emphasis and moments proportional to the radius of the model and the real thrusters, tied to the original geometry, is through the formalization of physical models of azimuthal thrusters with means for identifying degradation effects on the lines of the propeller flows by the methods of computational hydrodynamics.

Improvement of the structures of mathematical models of the SPP of the CPC, according to experimental data, is possible by measuring the input and output parametric coordinates of the thrusters of the CPC of the vessel operating in the dynamic positioning mode, with the estimation of the variance of the coefficients of the regression equations, and the construction of approximate analytical models of the CPC for determining the parameters of the control system of the CPC in within the framework of the development of DSS with the help of orthogonal compositional planning of the experiment, compilation of the corresponding matrix and obtaining the results in the form of the coefficient in the model.

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