# Synthesis of the management strategy of the ship power plant for the combined propulsion complex

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***Abstract*—Based on the calculations of the x-velocity components at the intersection of the screw flow along the rotation axis with the dimensions in units of the screw diameter for the vessel in dynamic positioning mode, the method of surface orientation of the Reynolds-Navier-Stokes equation for mass transfer on the separation line of the medium from different coefficients of properties. The limitation of power and torque on propeller shaft lines is ensured by the redistribution of the emphasis between the motors or the reduction of the maximum load. The three-level multicriterion strategy of energy distribution management in the hybrid marine power plant of the combined propulsion complex was developed by integrating the classical power management strategy with the strategy of management and monitoring of the state of the medium-speed diesel generator and the degree of charge of the alternative generator element of the energy accumulation system.**

***Keywords*—synthesis, management strategy, ship power plants, combined propulsive complex, effectiveness, functionality**

## 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.

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]:

$$\frac{\partial \vec{\upsilon}}{\partial t} = -(\vec{\upsilon}\nabla)\vec{\upsilon} + \nu_w \Delta\vec{\upsilon} - \frac{1}{\rho}\nabla P_v + \vec{f}_m; \quad \nabla \cdot \vec{\upsilon} = 0, \qquad (1)$$

where: $\nabla$ – nabla operator;
$\Delta$ – Laplace vector operator;
$t$ – time, [s];
$\nu_w$ – coefficient of kinematic viscosity, $\times 10^{-6}$ [m$^2$/s];
$\rho$ – the density of the environment, [kg/m$^3$];
$P_v$ – flow pressure, [Pa];
$\vec{\upsilon} = (\upsilon^1, \ldots, \upsilon^n)$ – 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[5]. To do this, the Reynolds equations are derived based on the Navier-Stokes equation, all members of which undergo averaging operation in time [6].

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 [7]. 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 $\upsilon_i$ 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, $0 < w_s < 0.4$:

$$F_p = \frac{\upsilon_i}{n \cdot D_p}, \tag{2}$$

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 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]:

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

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

$\boldsymbol{Z}^m = \boldsymbol{R}^m + p_ij\boldsymbol{L}^m$ — 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;
$\mu_R$ – index of viscosity of the medium, or index of friction, $\times 10^{-2}$[kg/m×s];
$\varepsilon$ – dialectical permeability of the environment, [Fa/m];
$\varepsilon_0$ – electrical constant, $8{,}8\times 10^{-12}$ [Fa/m];
$F_S(t)$ – force acting on the contact area, [H].

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]:

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

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

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

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 $\upsilon_a$ (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 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, 12].

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

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.

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

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

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

The values of the components of forces on the graphs are not presented, since the distribution is scaled for given traction and torque.

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:

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

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:

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

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

where $\beta_0$, $\beta_1$, $\beta_{ij}$ 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,

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

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 $\beta_0$, $\beta_1$, $\beta_{ij}$:

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

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

$$(X^T X) B = X^T Y, \qquad (15)$$

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 $\beta_0$, $\beta_1$, ..., $\beta_t$ 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

$$M^{-1}=\begin{bmatrix} s^2\{b_0\} & cov\{b_0b_1\} & \cdots & cov\{b_0b_m\} \\ cov\{b_1b_0\} & s^2\{b_1\} & \cdots & cov\{b_1b_m\} \\ .. & .. & .. & .. \\ cov\{b_mb_0\} & cov\{b_mb_1\} & \cdots & s^2\{b_m\} \end{bmatrix}. \quad (16)$$

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

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

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

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.

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.

## 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.

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 $\tau_T$ 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.

## REFERENCES


[1] Kobougias, I. PV Systems Installed in Marine Vessels: Technologies and Specifications: Research Article [Text] / I. Kobougias, E. Tatakis, J. Prousalidis // Advances in Power Electronics. – 2013. – 8 p. Doi:10.1155/2013/831560.

[2] Budashko, V. V. Modernization of hybrid electric-power system for combined propulsion complexes [Text] / V.V. Budashko, O.A. Onishchenko, D.V. Ungarov // Electrotechnic and computer systems. – 2016. – 23(99). – P. 17–22. Doi: 10.15276/eltecs.23.99.2016.02.

[3] Califano, A. Identification of ventilation regimes of a marine propeller by means of dynamic-loads analysis [Text] / A. Califano, S. Steen // Ocean Engineering. – 2011. – V. 38, I. 14–15. – P. 600–1610. Doi:10.1016/j.oceaneng.2011.07.009.

[4] Blais, B. A conservative lattice Boltzmann model for the volume–averaged Navier–Stokes equations based on a novel collision operator [Text] / B. Blais, J.–M. Tucny, D. Vidal, F. Bertrand // Journal of Computational Physics. – 2015. – V. 294. – P. 258–273. Doi:10.1016/j.jcp.2015.03.036.

[5] Budashko, V. Formalization of design for physical model of the azimuth thruster with two degrees of freedom by computational fluid dynamics methods [Text] / V., Budashko // Eastern-European Journal of Enterprise Technologies. – 2017. – V. 3. – № 7(87). – P. 40–49. Doi:10.15587/1729-4061.2017.101298.

[6] Jutao, C. Design and implementation of Marine Electric Propulsion Dynamic Load Simulation System [Text] / Jutao C., Huayao Z., Aibing Y. // 2008 3rd IEEE Conference on Industrial Electronics and Applications. – Singapore, IEEE, 2008. – P. 483–488. Doi:10.1109/ICIEA.2008.4582562.

[7] Saha, N. Speed control with torque ripple reduction of switched reluctance motor by hybrid many optimizing liaison gravitational search technique [Text] / N. Saha, S. Panda // Engineering Science and Technology, an International Journal. – 2016. – Doi:10.1016/j.jestch.2016.11.018.

[8] Mander, S. Slow steaming and a new dawn for wind propulsion: A multi-level analysis of two low carbon shipping transitions [Text] / S. Mander // Marine Policy, In Press, Corrected Proof, Available online. – 2016. Doi:10.1016/j.marpol.2016.03.018.

[9] Budashko, V. V. Design of the three-level multicriterial strategy of hybrid marine power plant control for a combined propulsion complex [Text] / V. V. Budashko / Electrical engineering & electromechanics. – 2017. – №2. – P. 62 – 72. Doi:10.20998/2074-272X.2017.2.10.

[10] Babadi, M. K. Effect of hull form coefficients on the vessel sea-keeping performance [Text] / M. K. Babadi, H. Ghassemi; Department of Ocean Engineering, AmirKabir University of Technology // Journal of Marine Science and Technology. – 2013. – 11 p. Doi:10.6119/JMST-013-0117-2.

[11] Budashko, V. V. Physical model of degradation effect by interaction azimuthal flow with hull of ship [Text] / V. V. Budashko, V. V. Nikolskyi, O. A. Onishchenko, S. N. Khniunin // Proceeding Book of International conference on engine room simulators (ICERS12). – Istanbul, Istanbul Technical University, Maritime Faculty, 2015. – P. 49–53. ISBN: 978–605–01–0782–1. Aviable at: \www/ URL: http://www.maritime.itu.edu.tr/icers12/program.htm

[12] Nikolskyi, V. The monitoring system of the Coanda effect for the tension-leg platform's [Text] / V. Nikolskyi, V. Budashko, S. Khniunin // Proceeding Book of International conference on engine room simulators (ICERS12). – Istanbul, Istanbul Technical University, Maritime Faculty, 2015. – P. 45–49. ISBN: 978-605-01-0782-1. Aviable at: \www/ URL: http://www.maritime.itu.edu.tr/icers12/program.htm.