Thrusters Physical Model Formalization with Regard to Situational and Identification Factors of Motion Modes

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***Abstract*—Research, diagnosis and prediction of the technical status of ships power plants (SPPs) of combined propulsion complexes (CPCs) depends on the corrective factors. They affect the thrust components and moments, the proportional dimensions of the models and the actual thrusters that correlate with the original geometry. The method of computational hydrodynamics has been im-proved as part of the study of diagnostic and forecasting tools for the SPP CPC technical condition. This made it possible to predict the degradation effects of the interaction of rowing flows between themselves and the CPC hulls. Theoretical provisions for the formation of energy process equations in CPC were developed in the course of analyzing the behavior of high-order multiphase non-stationary uncompressed propellers flows. Special laws of distribution of the necessary intensity of the most influential deformation effects were used. As a result, the number of difficulties associated with the nonlinearity of the method was avoided and real forms of azimuthal thrusts without any approximation. Also, due to the possibility of increasing the number of cross sections of the measure-ments, the effectiveness of the proposed methods of combating the above mentioned degradation effects was analyzed.**

***Keywords*—thruster, degradation effects, physical model, mathematical modeling, combined propulsion complexes, formalization.**

I. INTRODUCTION

During investigation of processes in the ship power plants (SPP) combined propulsion complexes (CPC) critical step for check adequacy mathematical and simulation models there is to create and perfection of physical models these SPP. Numer-ical methods for simulating threads with degradation effects, including the response of a ships engine, are modeled in the function of a diesel engine control system. The propellers torque, which is calculated by the model of the propellers with interaction with flow fields, is introduced into the model of the ship engine, then the speed of rotation of the propeller is ob-tained by solving the equation of rotational motion of the line of the propellers shaft. But such methods only allow to repro-duce the oscillations of the speed of rotation and the torque of the propellers in the conditions of ordinary swing, when the amplitude of the oscillations shows the correspondence with the measured data. It is also difficult to obtain experimental data on stream fields based on the movement of the ships [1]. The maximum range of the practical part of the research work they allow you to realize. Alternatively, with the use of computational hydrodynamics of different ship designs and propulsion at an early stage of the design process, the effects of the interaction can be studied economically. Design parameterization and multi-purpose ships optimization are a task with many uncertainties. Some techniques are to create a detailed parametric model that captures both the external and internal geometric characteristics of the ships, as well as the integration of a number of numerical tools specifically designed to determine the performance of each variant. This allows you to evaluate the many design features and limitations that are part of the optimization problem. In such approaches, embedding in the physical and financial environment model is applied, providing a more realistic representation of the solution site for the developer. However, such optimization methodologies, at the stage of development, do not allow to the minimization of the overall resistance of the ship due to the degrada-tion effects [2].

As a package of computational hydrodynamics in the work [3], the authors use the Marin ReFRESCO package, which is widely used for the visualization of streams in and around different objects. ReFRESCO solves RANS equations (aver-aged Reynolds Navier-Stokes equations) for multi-phase un-steady non compressible flows, supplemented by turbulence models and volume-fractional equations of convective diffusion for each phase, or as their levels mass transfer at the phase boundary. Current loads for typical marine ships in var-ious configurations are investigated using model tests and computational dynamics fluid dynamics (CFD) calculations. Model tests are conducted in test pools to obtain reference data, including environmental impacts. Numerical validation of the model and full-scale Reynolds numbers are carried out to quantify the numerical uncertainty of the results. Validation of numerical results is only possible by comparing the numerical results on the Reynolds model scale with the results of testing the model. The effects of Reynolds scaling are investigated by comparing the numerical results on a model scale with the full-scale Reynolds number. Using CFD calculations, current ship loads can be obtained with an accuracy of 10% compared to the measured results [4].

The equations are sampled using the finite volume method in physical space. The implementation is surface-oriented, which allows to generate grids with any number of faces or locally cleaned grids with hanging nodes. When rendering the stream from an azimuth thrusters SPP CPC, models are used in which the screw is presented as Actuator Disk (AD) [5]. Model AD replaces the propeller blades with an equivalent force distribution over the entire screw volume. Such the model is the application of RANS equations to the propellers model with the ability to obtain the results of simulation of flow from propulsion in open water, under the hull and at the end of the hull [6].

According to the ship information analysis, the types of screws used, the azimuth thrusters modifications, the SPP layout scheme and their structure as multi-barrier impedance distribution systems built with Flexible Alternative Current Transmission Systems (FACTS) technology and being the Western System Coordinating Council (WSCC), the application of computational hydro-distribution methods to track the degradation effects on the flow lines of propellers is preceded by the systematization of the necessary identification parameters and situational factors [7].

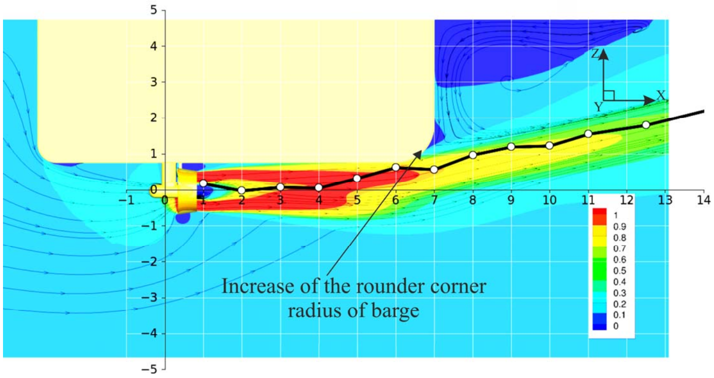

Figure 1. The appearance of degradation effect with the standard dismantling of the steering gear and increased radius somrounding of the body of the hold.

In Fig. 1 presents the flow characteristics and stack x-speeds of the 1500 kW model UL/ULE azimuth thrusters for the vessel with identification parameters and situational factors for free-water mode. Significant recirculation zones near the bilge rack are demonstrated, which causes significant loads on the rotating axis (baller) and the outer nozzle and confirms the need for complex energy calculation functions to be used at the crossings of energy flows from the SPP to the CPC movers. The most common types of azimuth thrusters typically perform two functions: propulsion and maneuverable. Before performing the research, it is important to clearly identify the differences between such devices and other types. The device is defined as a propulsion or maneuvering device, located outside the hull and containing the power of the rowing engine. It is necessary to distinguish the properties of such azimuthal propulsion complexes of bends, which are located in the hulls ship, and usually supply energy to the propellers through a system of shafts and helical gears [8].

Visualization of the power flows from the azimuthal propulsion was done according to the above procedure in Actuator Disk (AD), which shows the capture of the output flow to the lines of the recirculation zone along the rotating guides, which leads to the emergence of recirculation zones on the y-plane and identification of turbulence and identification of turbulence vortex viscosity μ_t/μ_w [9].

On the other hand, the recirculation zone mentioned above causes one of the degradation effects, the Coanda effect. [10] presents the comparative analysis of the trajectories of the x-velocity components of the azimuth thrusters propellers flow according to the results of measurements made at the intersection of the azimuth propellers flow along the axis of rotation with dimensions in units of propellers diameter D_r. However, it should be noted that in spite of the possibility of increasing the number of intersections of measurements, some points of the trajectory remain inaccessible, which makes it impossible to fully analyze the effectiveness of the proposed methods of combating the above effects.

Creating physical models of various objects is to comply with the hydrodynamic similarity there is the main problem in now. In accordance with the Kirpichev-Gukhman’s theorem of similarity hydrodynamic action will be similar if they [11]:

- the system of differential equations are describes;
- similar conditions of uniqueness are has;
- numerically equal similarity criteria are has [12, 13].

In particular, compliance with the geometric similarity to bridge independent of the size of the hydrodynamic properties is not enough.

II.PURPOSE OF WORK

The purpose of the researching is to formalize the similarity of the physical forces acting on the physical model of the thrusts and the real object, as well as the paramtrization of the inertial-hydrodynamic forces created for the unsteady fluid motion.

III. CONTENTS AND RESULTS OF THE RESEARCH

A. Technology of design and parameterization of thruster’s model.

The practical and physical impossibility of simultaneous execution conditions complete similarity makes us look for particular criteria of similarity, expressing conditions of similarity when the prevailing acts as one of the active forces [14, 15].

Depending on the tasks carried out by the ship, increasing the introduction on board vessels of various types of thrusters and azimuth propeller-rudder systems (AZIPOD), allows the use of dynamic position (DP) of three types [16, 17]. In any event, the creation of a physical model of the ship, a mode-DP, allows o consider hydrodynamic similarity with one of the predominant influence of the applied forces.

It is impossible to simultaneously satisfy the criteria are Reynolds and Froude for the same environment in the model and in nature. Anyway, when vessel work in DP and your velocity relative to the water surface is equal to zero, is predominant Froude criteria, unlike Reynolds. To eat, there is a hydraulic process of the interaction of a fixed-foot boat with waves and currents created by propellers [18, 19]. If the environment of the experiment will be different from the full-scale, one of the defining criteria should be the Archimedes criterion.

Euler's criterion for the retractable or tunnel thrusters can be decisive. In turn, the latter requires accounting criteria as defined in the Strouhal.

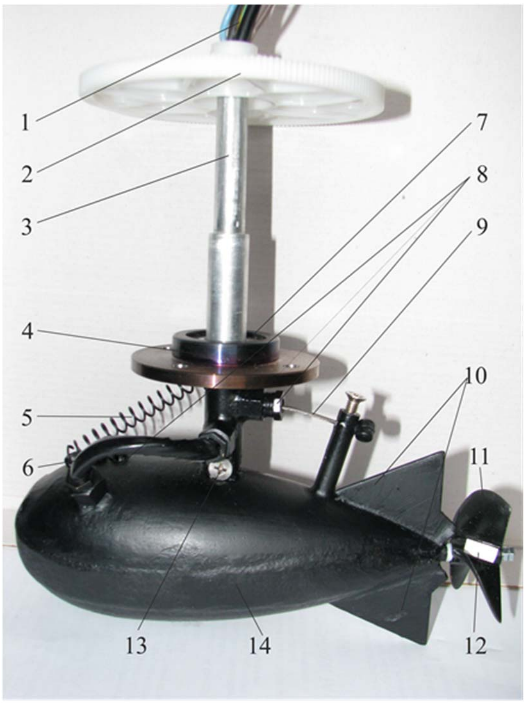

Figure 2. Physical model of the steering gear with two degrees of freedom: 1 – power cable rowing AD and cable to change the angle of inclination; 2 – the driving gear of the drive of turn of the baller; 3 – baller; 4 – bearing shield; 5 – the spring of feedback about change of an inclination; 6 – power cable; 7 – the bearing; 8 – stuffing boxes; 9 – cable for changing the angle of inclination; 10 – stabilization wings; 11 – FPP; 12 – is the fluorescent label for remote measurement of FPP rotation speed; 13 – connection point of the baller with the housing of the thruster; 14– is the thruster housing with the thruster located in the middle.

Based on the above, and given the fact that the geometric similarity observed, and the type, shape and number of propeller blades is not determinative criteria for individual thruster or AZIPOD as part of full-scale SPP CPC, you can build him quite adequate physical model.

For individual thruster or AZIPOD that operate with each other and to the vessel as a whole by means of the propeller thrust criterion Strouhal will trolled as a function of the Reynolds number lying in the range $200<Re<200000$. This constant Strouhal number: $Sh=0.2\div0.3$. For difference between the propeller thrust, the nature of this dependence is standing in for all flow conditions in the housing above a wide range of Reynolds numbers. This reflects the dominant role of vorticity in the poop area bad streamlined hull (limiting case - is cross-action to the flow) in the formation of the pressure field on its surface, and hence the energy losses

We accept the assumption that all of the electrical and thermal engines will be in full-scale-like, and for them to be sustained following constants: lu - zoom speeds; lt - time scale; lq - scale mass forces; le - length scale and a linear scale; for the environment: ln - coefficient scale kinematic viscosity and lr - scale density; and for the tunnel or retractable thrusters: lp - the scale of the pressure forces.

In accordance with the le, for the type of propeller, once identified the main-body model measures the rate of displacement of the vessel D = 100,000 tons and RMS-velocity movement in seawater v = 22 knots. Arrange housing thruster type Azipod as the streamlined nacelle with proportional sizes, with stern device and baller is designed (Fig. 2).

Keeping velocity scale lu were selected: reduction gear for the on-gate rudder for speed rudder from side to side about 2°/sec and an electric motor with reduction gear for driving screws on 0÷300 rev/min, and to meet the scale of the mass forces lq housing AZIPOD model in proportion to the lead-filled was weighted.

Motor Hobbywing QUICRUN Sensored BursHless Combo 13.5T Motor + 60A ESC 2500KV RC CAR – brushless three-phase low-resistance high-reflex with the following characteristics: RPM/Volt (KV) – 2500; rated current – 60A; peak current – 380A; Model: QUICRUN-3650-25.5T; LiPo Cells: 2~3S; outer diameter/length: 36 mm/52,8 mm; R.: 0,1; No-load Current: 1.1; Diameter of the Shaft: 3.17 mm; Poles: 2.

Specifications of ESC: Brand: SkyRC; Motor compatible: Brushless sensor/sensorless ESC Car compatible:1/10 and 1/12 Buggy and Touring Car Power supply: 2-3S LiPo battery, 4-9S NiMh battery BEC output: 6V/3A; Constant current: 60A; Burst current: 380A; Resistance: 0.0007 Ohm; Fan: 8V/0.2A, Max 12.6V.

Instructions for use, connection and programming the controller, as well as span of control channels when you first start a new regulator, using a controller with a new receiver or when changing the neutral position of the transmitter, as well as other parameters are given in [20, 21].

There are wiring diagrams rudder servo rotation, exuding nick-power and controls the electric drive of the shaft and a table selection controller mode, depending on the requirements of technological process [22-24].

One of the most promising concepts SPP CPC is a hybrid board installation with contra-rotating propellers (Contra-Rotating Pod, CRP), operating in DP mode. It is dominated by the gravitational force and the law of Froude similarity, which is necessary for compliance with the equality of numbers for the model and nature, i.e., $Fr_M = Fr_H$ and similarity criteria must be expressed in terms specific to the mode value. When the water flow around the hull as the characteristic measure of the linear time-selected length of the vessel between perpendiculars at the waterline and the precipitate in the flow direction, and as the characteristic velocity - flow rate of attack.

Accounting cavitation is carried out in compliance with the criteria of similarity Fr, Re and equality of the numbers Eu for the model and vessel. Thus, the thrust of propeller for model and the vessel should be in the relationship:

B. *Technology of design and parameterization of thruster's model.*

Froude similarity criteria for our case we get from the general criterion of hydrodynamic similarity of Newton, substituting in this equation the gravity, G = mg:

$$\frac{v_S^2}{g_S \times l_S} = \frac{v_M^2}{g_M \times l_M}, \tag{1}$$

where: v – the speed of the incoming flow, m/sec; g – gravity, m/sec^2; l – length, m; respectively (S) – of the ship and (M) – of the model.

From equation (1) is necessary to obtain the basic parameters of any emerging flows, taking into account the extent of similarity. We calculate at what rate are based, thrust and torque for the model and ship are modeled on the law of Froude.

If the field conditions and the conditions of the test model the acceleration of gravity $g_S \neq g_M$, then (1) follows:

$$\frac{v_S}{v_M} = \sqrt{\frac{l_S \times \rho_1}{l_M \times \rho_2}} = \sqrt{\lambda_{SM}}, \tag{2}$$

where ρ_1, ρ_2 – density of the environments, kg/m3, since the rate for the model of flow of water should be reduced to $\sqrt{\lambda_{SM}}$, provided Archimedes criterion for natural environment and simulation environment.

$$\frac{T_S}{T_M} = \frac{n_S \times v_S}{n_M \times v_M} = \lambda_{SM}^2 \sqrt{\lambda_{SM}} = \lambda_{SM}^{2,5}, \tag{3}$$

where n_S, n_M – RPM of propellers shaft, RPM/min; since the thrust of the ship propeller T_S, then at a lower l_{SM} times model, propeller thrust must be less to $\lambda_{SM}^{2,5}$ times subject to the criterion of geometrical similarity.

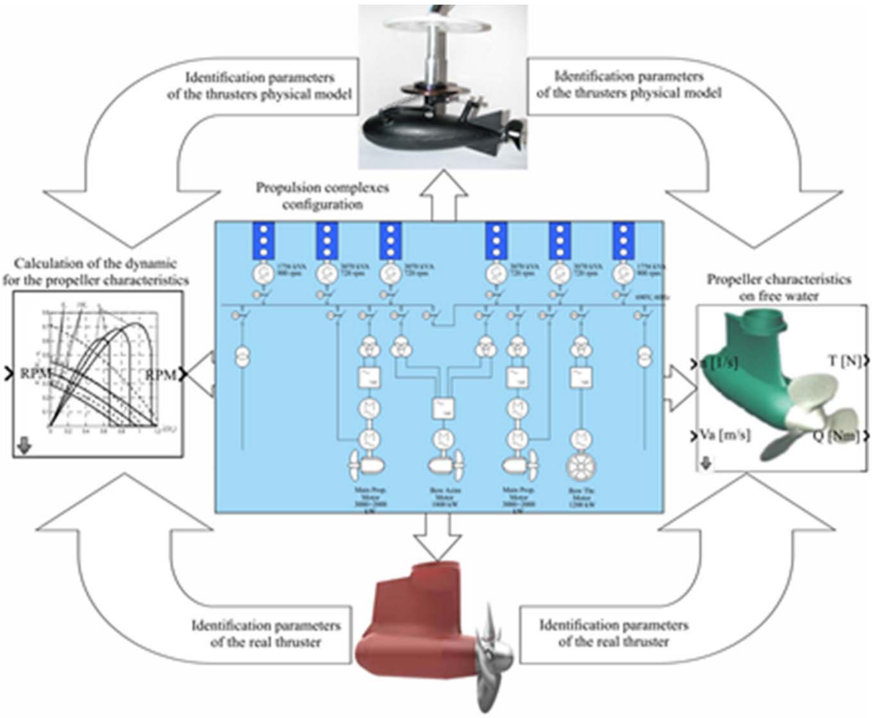

Figure 3. Visualization of the process of formalization for thrusters physical models with determination of the configuration for the combined propulsion complex.

The ratio of the moments on the shafts of the propeller, and consequently consumed by drive motors capacity, taking into account the ratio of (1) and (2) is equal to:

$$\frac{Q_S}{Q_M} = \frac{D_S \times v_S}{D_M \times v_M} = \lambda_{SM}^{2,5} \sqrt{\lambda_{SM}} = \lambda_{SM}^3, \tag{4}$$

where D_S, D_M – diameter of propeller, m.

The process of formalization of physical models is given Fig. 3. Using the full set of parameters here is faster in exceptional cases than in one of the automatic modes. At the same time, the decision-maker is guided by the accumulated experience and systematic typical situational factors with which current situations arise.

Based on (1) - (4), a system of equations that describes the electromagnetic and electromechanical processes in the thruster's propulsion's motor and takes the nonlinear nature of the processes in the motors is of the form (5), where m – is the number of phases; p – is the number of pairs of poles; U_{1s}, U_{2s} – are components of the stator voltage; Ψ_{1s}, Ψ_{2s}, Ψ_{1r}, Ψ_{2r} – are components of the stator and rotor coupling; I_{1s}, I_{2s}, I_{1r}, I_{2r} – are the constituent currents of the stator and rotor; R_s, R_r, – are the active stator and rotor supports, M_d – is the induction motor torque:

$$\begin{cases} U_{1s} = \lambda_{SM}^{2,5}\left(\frac{d\Psi_{1s}}{dt} - \Psi_{2s}\omega_k\right) + \frac{R_s I_{1s}}{\lambda_{SM}^{2,5}} \\ U_{2s} = \lambda_{SM}^{2,5}\left(\frac{d\Psi_{2s}}{dt} - \Psi_{1s}\omega_k\right) + \frac{R_s I_{2s}}{\lambda_{SM}^{2,5}} \\ 0 = \lambda_{SM}^{2,5}\left(\frac{d\Psi_{1r}}{dt} - (\omega_k - p\omega)\Psi_{2r}\right) + \frac{R_r I_{1r}}{\lambda_{SM}^{2,5}} \\ 0 = \lambda_{SM}^{2,5}\left(\frac{d\Psi_{2r}}{dt} + (\omega_k - p\omega)\Psi_{1r}\right) + \frac{R_r I_{2r}}{\lambda_{SM}^{2,5}} \\ M_d = \lambda_{SM}^{2,5}\left(\frac{mpK_r}{2}\left|\Psi_r \times I_s\right|\right)\left|\left(1 - \lambda_{SM}^{2,5}\right)\right| \end{cases}; \tag{5}$$

Similarly, a scale can be used to calculate the scale value for a ship's dynamics model (Fig. 4).

In the real world, when there are restrictions on the magnitude of the stops created by the propulsion engines and the speed of their change, it is unacceptable to use a control law that would be optimal in the absence of these restrictions. With restrictions on the level and speed of changing the control stops, the positioning accuracy is significantly lower than in the absence of restrictions.

In the presence of restrictions on the control stops to ensure a small amount of displacement of the vessel, it is necessary to recalculate the stops to prevent a significant change in the torque relative to the desired value.

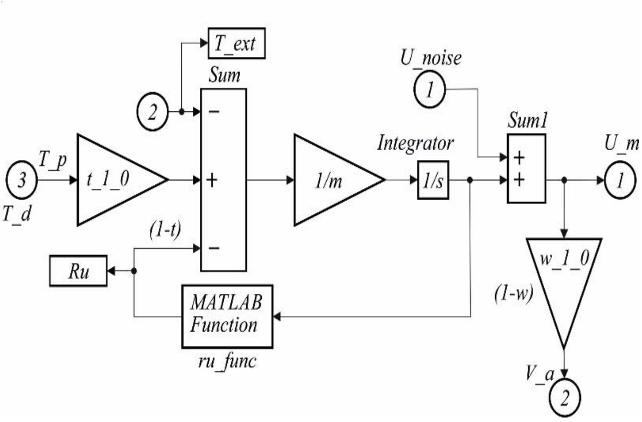

Figure 4. – Model ship dynamics: T_d – thrust of propeller; t_1_0 = 1 – t = the average value of the thrust deduction coefficient, p.u., measured data for the proper model ship; T_ext – thrust of the external Force; m = 10009*1025 (displacement*the specific gravity of marine water) + weight of the load; U_noise – noise of the speed vessel; Ru_func – the function of calculating the resistance movement of the ship (Ru); w_1_0 = 1 – w = the average value of the wake fraction deduction coefficient, p.u., for the corresponding model ship; U_m – the ship's speed, knots.

The algorithm of formation of control influence for stabilization of the ships in the conditions of restrictions does not affect the power of the propulsive complex and the speed of its change. The algorithm used the simplex method with a large number of steering devices. High efficiency of the algorithm is confirmed when used in the simulation model.

With restrictions, the temporal smoothing of the measurements used in the design of the stabilization control results in only a slight decrease in the average displacement.

For dynamic stabilization at equilibrium time smoothing of measurements at a finite interval, the average power consumption is found to be greater, and the accuracy of stabilization is worse than at Kalman filtration with different nature of external disturbances.

IV. THE RESULTS OF RESEARCH.

The adequacy of the physical model using MatLab/Simulink was checking, with the help of software Ships_CPC, developed in the framework of research work of the state budget "Concept of technology and ways of improving ship power plants combined propulsion complexes" at the Electromechanics and Electrical Engineering department of National University “Odessa Maritime Academy” (Fig. 3). If CPP CPC operates in DP, ship model, the so-called m-file "is generated" with computer applications WAMIT (Wave Analysis Massachusetts Institute of Technology) [25-27] and is a functional unit that connects between the result vector of trust tau, for example, six electrical motors of thrusters with three degrees of freedom (3 degrees of Freedom (DOF) control vector) to the output of meter dynamic positioning vessel, where: U – travel speed, m/sec; V – speed transverse displacement, m/sec; r – yawing rate, rad/sec; x – x-position, м; y – y-position, м; psi – yawing angle, rad.

V. ACKNOWLEDGEMENTS

The author designed and implemented a model in computer laboratory, which is used in study process and permits to solve main tasks of project and exploitation of combined propulsion complexes. The engineering theory “Controlling system for asynchronous thrust motors” has been developed and implemented in practice, methodical recommendation “Ship’s electrical drives for DP vessels” and “Ship’s automated drives” for courses of laboratory has been published. A tutorial “Power electrical machine for AZIPOD devices” has been published with preliminary recommendation and legalization of Academic council of National University “Odessa Maritime Academy”.

VI. CONCLUSIONS AND RECOMMENDATIONS

The ratios of the THRs CPC ratios are better correlated with the power ratios than the stepping screw ratios, which gives reason to believe that the efficiency of the SPP CPC’s energy efficiency is increased in operational modes and allows the results to be added to the database of decision support systems (DSS) for developers and research new concepts of the SPP CPC’s or to modify existing ones [28]. Determining the magnitudes of the stresses attached to the vessel and forming the configuration matrix of the THRs with determining the distance from the point of application of the emphasis of the individual THRs to the projection of the force vector on the plane of motion of the vessel is possible based on the study of the internal properties of the components of SPP CPC’s operating in the mode of dynamic positioning relevant identification factors.

The dependence of the correction factors affecting the components of the stops and moments, proportional to the radius of the model and the real THRs, bound to the original geometry, is obtained by formalizing the physical models of the azimuthal THRs with the means of identifying the degradation effects on the flow lines of the rotor screwdrivers [29].

Improvement of structures of mathematical models of SPP CPC’s according to experimental studies is possible by measuring the input and output parametric coordinates of the THRs CPC of the vessel operating in the mode of dynamic positioning, with the estimation of the variances of the coefficients of the regression equations, and the construction of the approximate control parameters of the CPC as part of the design of the DSS using orthogonal composite experiment planning, drawing up the appropriate matrix and obtaining the results in the form of a coefficient in the model [30, 31].

REFERENCES

[1] Ohashi, K. Development of numerical method to simulate flows around a ship at propulsion conditions in regular waves coupling with the ship propulsion plant model [Text] / K. Ohashi // Applied Ocean Research. – 2018. – V. 73. – P. 141-148. ISSN 0141-1187. Doi: 10.1016/j.apor.2018.02.006.

[2] Priftis, A. Multi-objective robust early stage ship design optimisation under uncertainty utilising surrogate models [Text] / A. Priftis, E. Boulougouris, O. Turan, G. Atzampos // Ocean Engineering. – 2020. – V. 197. – Article 106850. ISSN 0029-8018. Doi: 10.1016/j.oceaneng.2019.106850

[3] Ma, P. Fracture analysis of an electrically conductive interface crack with a contact zone in a magnetoelectroelastic bimaterial system [Text]

/ P. Ma, R.K.L. Su, W.J. Feng // International Journal of Solids and Structures. – 2015. – V. 53. – P. 48–57. Doi:10.1016/j.ijsolstr.2014.10.024.

[4] Koop, A. Using CFD to determine scale effects on current loads of offshore vessels in side-by-side configuration [Text] / A. Koop // Ocean Engineering. – 2020. – V. 195. Article 106707. ISSN 0029-8018/ Doi: 10.1016/j.oceaneng.2019.106707.

[5] Nguyen, V. T. Modelling turbulence with an Actuator Disk representing a tidal turbine [Text] / V. T. Nguyen, S. S. Guillou, J. Thiébot, A. S. Cruz // Renewable Energy. – 2016. – V. 97. – P. 625–635. Doi:10.1016/j.renene.2016.06.014.

[6] Shives, M. Adapted two-equation turbulence closures for actuator disk RANS simulations of wind & tidal turbine wakes [Text] / M. Shives, C. Crawford // Renewable Energy. – 2016. – V. 92. – P. 273–292. Doi:10.1016/j.renene.2016.02.026.

[7] Sturge, D. A hybrid actuator disc – Full rotor CFD methodology for modelling the effects of wind turbine wake interactions on performance [Text] / D. Sturge, D. Sobotta, R. Howell, A. While, J. Lou // Renewable Energy. – 2015. – V. 80. – P. 525–537. Doi:10.1016/j.renene.2015.02.053.

[8] Carlton, J. S. Chapter 15 - Azimuthing and Podded Propulsors [Text] / J.S. Carlton // Marine Propellers and Propulsion (Fourth Edition), Butterworth-Heinemann. – 2019. – P. 389-398. ISBN 9780081003664. Doi: https://doi.org/10.1016/B978-0-08-100366-4.00015-8.

[9] Thiébot, J. Modelling the effect of large arrays of tidal turbines with depth-averaged Actuator Disks [Text] / J. Thiébot, S. Guillou, V. T. Nguyen // Ocean Engineering. – 2016. – V. 126. – P. 265–275. Doi:10.1016/j.oceaneng.2016.09.021.

[10] Budashko, V. Theoretical-applied aspects of the composition of regression models for combined propulsion complexes based on data of experimental research [Text] / V. Budashko, V. Golikov // Eastern-European Journal of Enterprise Technologies. – 2017. – V. 4. – № 3(88). – P. 11 – 20. Doi:10.15587/1729-4061.2017.107244.

[11] Kuneš, J. 5 – Thermomechanics [Text] / J. Kuneš // Dimensionless Physical Quantities in Science and Engineering, Elsevier. – 2012. – P. 173-283. ISBN 9780124160132. Doi:10.1016/B978-0-12-416013-2.00005-1.

[12] Fu, J. Multi-level virtual prototyping of electromechanical actuation system for more electric aircraft [Text] / J. Fu, J.-C. Mare, L. Yu, Y. Fu / Chinese Journal of Aeronautics. – 2018. – V. 31, I. 5. – P. 892-913. ISSN 1000-9361. Doi: 10.1016/j.cja.2017.12.009.

[13] Fu, J. Modelling and simulation of flight control electromechanical actuators with special focus on model architecting, multidisciplinary effects and power flows [Text] / J. Fu, J.-C. Maré, Y. Fu // Chinese Journal of Aeronautics. – 2017. – V. 30, I. 1. – P. 47-65. ISSN 1000-9361. Doi: 10.1016/j.cja.2016.07.006.

[14] Kühnel, N. Implementing an adaptive traffic signal control algorithm in an agent-based transport simulation [Text] / N. Kühnel, T. Thunig, K. Nagel // Procedia Computer Science. – 2018. – V. 130. – P. 894-899. ISSN 1877-0509. Doi: 10.1016/j.procs.2018.04.086.

[15] 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.

[16] Budashko, V. Multicriteria strategy of power managing system for ships power plants for combined propulsion complexes [Text] / Budashko V. // IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE). – 2019. – V. 14, I. 5. – P. 14-28. e-ISSN: 2278-1676, p-ISSN: 2320-3331. Doi: 10.9790/1676-1405011428.

[17] 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.

[18] Prabhu, J. J. On the hydrodynamic loading of marine cycloidal propeller during maneuvering [Text] / J.J. Prabhu, A.K. Dash, V. Nagarajan, O.P. Sha // Applied Ocean Research. – 2019. – V. 86. – P. 87-110. ISSN 0141-1187. Doi: 10.1016/j.apor.2019.02.008

[19] Budashko, V. Decision support system's concept for design of combined propulsion complexes [Text] / V. Budashko, V. Nikolskyi, O. Onishchenko, S. Khniunin / Eastern-European Journal of Enterprise Technologies. – 2016. – V. 3. – № 8(81). – P. 10 – 21. Doi:10.15587/1729-4061.2016.72543.

[20] Thieme, C. A. Assessing ship risk model applicability to Marine Autonomous Surface Ships [Text] / C. A. Thieme, I. B. Utne, S. Haugen // Ocean Engineering. – 2018. – V. 165. – P. 140-154. ISSN 0029-8018. Doi: 10.1016/j.oceaneng.2018.07.040.

[21] Zubowicz, T. Marine autonomous surface ship - control system configuration [Text] / T. Zubowicz, K. Armiński, A. Witkowska, R. Śmierzchalski // IFAC-PapersOnLine. – 2019. – V. 52, I. 8. – P. 409-415. ISSN 2405-8963. Doi: 10.1016/j.ifacol.2019.08.100.

[22] Tsarau, A. A numerical model for simulating the effect of propeller flow in ice management [Text] / A. Tsarau, R. Lubbad, S. Løset // Cold Regions Science and Technology. – 2017. – V. 142. – P. 139-152. ISSN 0165-232X. Doi: 10.1016/j.coldregions.2016.06.002.

[23] Tran, D.-D. Thorough state-of-the-art analysis of electric and hybrid vehicle powertrains: Topologies and integrated energy management strategies [Text] / D.-D. Tran, M. Vafaeipour, M. E. Baghdadi, R. Barrero, J. V. Mierlo, O. Hegazy // Renewable and Sustainable Energy Reviews. – 2019. – Art. 109596. ISSN 1364-0321. Doi: 10.1016/j.rser.2019.109596.

[24] Babicheva, T.S. The Use of Queuing Theory at Research and Optimization of Traffic on the Signal-controlled Road Intersections [Text] / T.S. Babicheva // Procedia Computer Scienceю – 2015. – V. 55. – P. 469-478. ISSN 1877-0509. Doi: 10.1016/j.procs.2015.07.016.

[25] Wang, W. A two-stage framework for the optimal design of a hybrid renewable energy system for port application [Text] / W. Wang, Y. Peng, X. Li, Q. Qi, P. Feng, Y. Zhang // Ocean Engineering. – 2019. – V. 191. – Art. 106555. ISSN 0029-8018. Doi: 10.1016/j.oceaneng.2019.106555.

[26] Yang, C. Adaptive real-time optimal energy management strategy based on equivalent factors optimization for plug-in hybrid electric vehicle [Text] / C. Yang, S. Du, L. Li, S. You, Y. Yang, Y. Zhao // Applied Energy. – 2017. – V. 203. – P. 883-896. ISSN 0306-2619. Doi: 10.1016/j.apenergy.2017.06.106.

[27] A. Najafi, B. F. Spencer Adaptive model reference control method for real-time hybrid simulation [Text] / A. Najafi, B. F. Spencer // Mechanical Systems and Signal Processing. – 2019. – V. 132. – P. 183-193. ISSN 0888-3270. Doi: 10.1016/j.ymssp.2019.06.023.

[28] Hu, X. Experimental studies of the unsteady hydrodynamic loads on a tension-leg platform at high Reynolds numbers [Text] / X. Hu, X. Zhang, Y. You // Journal of Fluids and Structures. – 2019. – V. 87. – P. 263-283. ISSN 0889-9746. Doi: 10.1016/j.jfluidstructs.2019.03.024.

[29] Budashko, V. Synthesis of the Management Strategy of the Ship Power Plant for the Combined Propulsion Complex [Text] / V. Budashko, V. Shevchenko // 2018 IEEE 5th International Conference on Methods and Systems of Navigation and Motion Control (MSNMC), Kyiv, 16-18 Oct. 2018, Ukraine: IEEE. P. 106-108. Doi: 10.1109/MSNMC.2018.8576266. Aviable at:\WWW/ URL: https://ieeexplore.ieee.org/document/8576266.

[30] Budashko, V. Вдосконалення стратегії управління багатомасовою електромеханічною системою [Текст] / V. Budashko, V. Shevchenko // Wschodnioeuropejskie Czasopismo Naukowe (East European Scientific Journal). – 2019. – V. 9 (49). – P. 38-43. Aviable at: \WWW/ URL:https://eesa-journal.com/wp-content/uploads/EESA_september_part_3.pdf.

[31] Budashko, V. V. Increasing the efficiency of hybrid propulsion complexes for multipurpose vessels by different criteria of the energy management strategies [Text] / V. V. Budashko // Wschodnioeuropejskie Czasopismo Naukowe (East European Scientific Journal). – 2019. – V. 10 (50). – P. 53-62. Aviable at: \WWW/ URL: https://eesa-journal.com/wp-content/uploads/EESA_1050_oct_2019_part_4.pdf.