Main problems of creating energy-efficient positioning systems for multipurpose sea vessels

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***Abstract*—The main problems of functioning of sea multi - purpose sea vessels in the modes of dynamic stabilization of the set geographical position are given in the work. The identified solutions are based on the proposal of modern automated control systems of ship power plants of multi-purpose ships, which provide significant dynamic energy reserve, high accuracy of ship stabilization with wide changes in external loads, versatility and ability to perform technological tasks for various purposes.**

Keywords—dynamic positioning, ship power plant, stabilization, combined propulsion complex.

I. Introduction

The complex use of diesels with electronic injection, brushless generators, electric propulsion type AZIPOD theoretically allow the creation of ships with high-precision dynamic stabilization of the given geographical position (DP) in severe hydrometeorological conditions. Prerequisites for multi-purpose use, such as offshore drilling rigs with weapons or special equipment systems, are emerging. The processes of energy efficient energy transfer in the power plants of multipurpose vessels with combined propulsion complexes (CPC) are almost not studied. Ship power plants (SPP), created for specific types of ships with chipboard, have special requirements for energy consumption and energy efficiency. The multifunctional capabilities of chipboard vessels can be used only to a limited extent, because their efficient operation requires power that significantly exceeds that of modern SPPs with no chipboard systems. The conceptual development of the SPP of such vessels with chipboard is final in the creation of specialized CPCs, the use of special types of electric drives, the use of specialized energy sources and controls.

High-precision dynamic retention of the position by the vessel while maintaining the energy efficiency and stability of the SPP CPC, provided that the vessel performs the main function is problematic. There is a contradiction and demand of practice – to achieve maximum energy efficiency while maintaining the objectives of safety, ecology and, most importantly – the implementation of the main technological task of a multipurpose vessel. Even the preliminary analysis [1-6] shows that the use of special controls and modified CPCs will lead to at least the 30% increase in the efficiency of power conversion from energy sources to propellers. But this problem is not solved by methods of almost uncontrolled counteraction of the force of the propeller stop due to the coordinated counterbalance to external perturbation.

Most of the available recommendations for assessing the characteristics of the CPC SPP, calculating engine power and determining their type (design bureau "South", Ukraine), complete set of propulsion complex engines of various types obtained on the basis of empirical experience of design and operation, as well as statistical processing of information on ships (private joint-stock company "Chernomorsudnoproekt", Ukraine).

Analysis of the current state of research, approaches and methodology [7-10], solving problems of improving the efficiency of vessels with DP, SPP CPC for various purposes (international concerns Wartsila, Danfoss) do not allow to confidently declare a solution to the problem of reducing efficiency and increasing failures during normal operation of vessels and in the modes of the DP. The generalization of the results of studies of the performance characteristics of ships with CPC and particleboard, performed by different authors [1, 3, 7-9], and their methods do not allow with sufficient accuracy to perform calculations of running and dynamic qualities of ships for different purposes. Model and field tests of propellers, empirical methods for determining the resistance, as well as the calculation and design of engines of various types, cause complex, unresolved issues of interaction of propellers with the hull [2, 5, 7].

Hydrometeorological factors and uncertainties related to the area of navigation, season, fuel prices, oil, crew consistency, etc. have the significant impact on the efficiency of DP systems, their SPP and CPC. Thus [1, 3, 4, 7, 10]:

– the issues of substantiation of the type, determination of the optimal (rational) architecture and main characteristics of the CPC in the implementation of SPP projects are not given enough attention, and most existing methods of assessing the effectiveness of SPP are used outside the systematic approach to design, do not always meet modern requirements. proposed solutions [1, 3, 4];

– the promising direction in the implementation of work related to improving the efficiency of DP, SPP and CPC systems is the use of modern simulation environments and CAD/CAM/CAE-systems, which allows to take random factors and dynamics of the environment for the operation of DP systems [4, 7, 9];

– relevant for multi-purpose vessels and dual-use are the issues of increasing the reliability and efficiency of the CPC SPP with guaranteed performance of technological tasks by the vessel [8-10];

– insufficiently covered issues related to the automation of work on the design and technological preparation of production in projects to improve the efficiency of the CPC SPP multi-purpose vessels.

II. Purpose of work

Research of processes of energy-saving dynamic positioning, control, conversion and energy transfer in SPP CPC of multi-purpose vessels with improvement of systems, hardware and software, development of methods of guaranteed performance of special and basic technological tasks of multi-purpose vessels under the condition of high energy efficiency of functioning of their SPP of the CPC working in various difficult operational modes..

III. Contents and results of the research

The authors proposed improved methods and algorithms for monitoring and control of the moment of the CPC SPP (for example, patents of Ukraine №100819 from 10.08.2015, №107006 from 03.06.2016, №108074 from 26.06.2016) and construction the synergistic structure of the control system [11-20], theoretically allow to solve the problem of optimizing the process of controllability of the chipboard system while increasing the efficiency of power transmission to the propellers, increasing reliability and expanding functionality, in particular – dual-purpose vessels.

Advanced control algorithms [11-16] allow, based on the application of independent input load characteristics, to generate propeller torques, implement the necessary control signals taking the location of active thrusts relative to the hull, quickly reconfigure environmentally dependent parameters. Given the results of similar researches [21], dependences of crossing of typical situations for operational modes were received for SPP CPC [18]:

$$\begin{aligned} & d_i=0;\ a_{ij}=0;\ j=0;\ j=1,2,...,L; \\ & \exists k=1,2,...,L;\ p_{is}\in P_{ik},\ s=1,2,...,S \Rightarrow \\ & \Rightarrow d_i=1;\ b_{ks}=1;\ a_{ik}=1; \\ & \overline{C}_{ik}\bigcup \overline{C}_{ij},\ j=1,2,...,L; \end{aligned} \quad (1)$$

where: d_i, b_s and a_j – auxiliary indicator variables of the iterative process;
p_{is} – s-th sign of the situational factor;
P_{ik} – the set of characteristic features of the k-th typical situation factor for the i-th operating mode identifier;
$\overline{C}_{ik}$ – set of variables taken into account in the modified task;
$\overline{C}_{ij}$ – an average set of typical situational factors for which $a_{ij} \neq 0$.

Based on the obtained dependences [17, 18], the authors created the reduced (1:50) physical model of the multifunctional propulsion complex with a DP system, which proved the effectiveness of the proposed solutions. At the level of technical implementation in the links of orientation, stabilization, navigation and control of the authors, the use of such elements as solid wave gyroscopes and piezoelectric transducers has been introduced and, unlike traditionally used devices in BF systems, can operate in independent angles. and speed [16-20].

The study of the principles of synthesis and operation of DP systems equipped with CPCs reveals the widespread use of typical PID-controllers in different circuits of the control system, despite the significant shortcomings – the complexity of parameterization, noise sensitivity, unreasonable energy consumption and others [22-25].

There is no open access analysis of multi-purpose vessels (dual-purpose vessels). It is known [3, 10] that in some systems of DPS1 type it is possible to "shut down" the main and auxiliary engines, thrusters, and all the same the vessel will keep a position even in difficult weather conditions. Sometimes [5] the operation of ships with DP systems (type DPS2), where there is a global satellite navigation system (GNSS) with a FanBeam device and a working autopilot, is reduced to the operation of the algorithm DPS1. On state-of-the-art beta versions of K-POS systems [6, 8, 9], the ship will be very difficult to steer in some situations. Increasing the speed of the DP system gives significant technological advantages, but the energy efficiency of such DP systems is very questionable [3-5].

Assuming that the service requests of the system's DP sensors have a Poisson nature of the flow of requests and the laws of service, then the flow of events in the DP system must have three properties: normal, no effect and stationary, and obey the law of Poisson's propagation [17, 18]:

$$P_n(\tau) = (\lambda\tau)^n \cdot e^{-\lambda\tau} / n!, \quad (2)$$

where: $P_n(\tau)$ – the probability of occurrence of n homogeneous events in the time interval τ;
λ – the constant positive number that defines the average number of events per unit of time.

Thus, the solution of the problem of improving the energy efficiency of multi-purpose vessels with DP, for example, type LEGDPS: a) providing the necessary, technologically determined, positioning accuracy (for example, to ensure the operation of guidance systems); b) taking into account the action of external disturbances in the open sea, is relevant, has practical significance and is not conceptually resolved.

Improving the accuracy of dynamic positioning systems of special ships allows to use them for multipurpose purposes, which can be done through the simultaneous use of energy efficient management methods by: a) construction the special structure of SPP and CPC, b) using real-time model in the control loop, c) appropriate corrective actions by means of the forecast analysis of mutual influence of operational parameters of separate elements of SPP and CPC.

For example, for the specified DP systems according to (1) and (2), many typical situational factors will have intersections, which affects the adjustment of the corresponding coefficients of PID-regulators, ie [26, 27]:

$$\begin{aligned} & \overline{C}_{ik}\bigcap \overline{C}_{ij} = \not\in,\ k=1,2,...,L; \\ & j=1,2,...,L;\ k\neq j. \end{aligned} \quad (3)$$

where: $\overline{C}_i$ – the set of situational factors of the operating mode;
L – the subset $\overline{C}_i$, k = 1, 2, ..., L, relevant to typical situational factors. All current situations are evaluated for belonging to a particular set $\overline{C}_{kj}$, k = 1, 2, ..., L, and the task is replaced by the task equivalent to the typical situation $\overline{C}_{kj}$.

According to the results of research, the following are determined: a) criteria for assessing the quality of power transmission from energy sources to propulsion systems in the CPC SPP in different operating conditions; b) methods for forecasting excess power consumption during changes in the operational regime of dual-use vessels; c) criteria for assessing the derivation efficiency of CPC engines in order to improve the energy performance of SPP and to develop a methodology for matching the characteristics of engines and engines of CPC for the projected analysis of power conversion processes in SPP.

In particular, taking (1) and (3), for the set of situational factors $\overline{C_{kj}}$ of the operating mode, we define the corresponding intersections for k = 1, 2, ..., L, s = 1, 2, ..., S. Indicator variables of the iterative processes d_i, b_s, and a_j change arbitrarily within the set of characteristic features of the k-that typical situational factor for the i-th identifier of the operational mode P_{ik} (Fig. 1). The set of variables of the modified problem is an intersecting set of typical situational factors for which $a_{ij} \neq 0$.

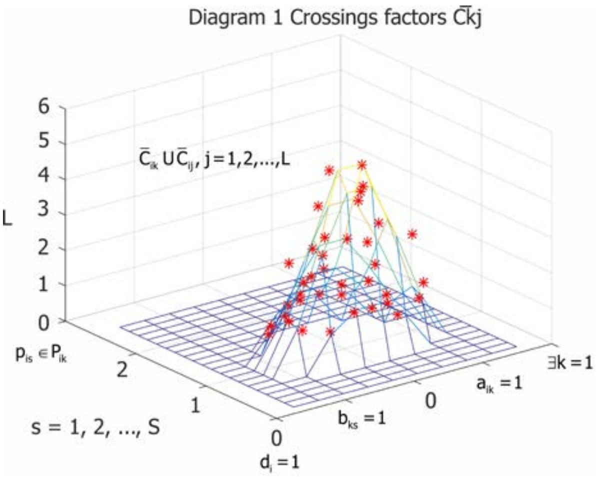

Fig. 1. The intersections of the set of situational factors $\overline{C_{kj}}$ of the operational mode for k = 1, 2, ..., L, s = 1, 2, ..., S.

Mathematical models have been developed: a) power transfer in the CPC SPP of different types, which will allow assessing the energy efficiency and quality of processes in the chipboard of ships equipped with different types of electric motors and propulsion and choose the most efficient solution; b) SPP of the CPC, taking random factors with justification of the type and main characteristics of the SPP.

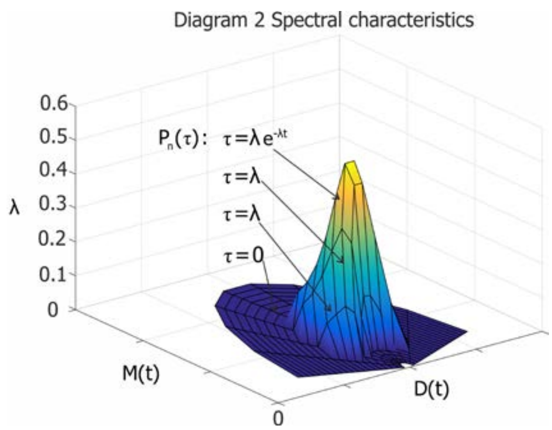

Fig. 2. Mathematical expectation of the situational factor that will cause the system to exit from the stable state.

The developed methods are: a) prediction of possible operational reduction of efficiency of functioning of motors of SPP and motors of CPC at the chipboard with accuracy essentially bigger, than existing; b) structural and parametric identification of SPP and CPC based on the results of operational observations using DMI-models in order to achieve maximum energy efficiency of controls; c) automated design of CPC SPP, based on the use of modern CAD/CAM/CAE-systems. In Fig. 2 shows the spectral characteristic of mathematical expectation of the occurrence of the certain situational factor, which will lead to the exit of the system from the stable state [17, 18].

IV. Conclusions and Recommendations

1. Direct torque controllers such as Direct Torque Control or vector speed controllers [28] (for example, Vector Oriental Control) and the like, the models of which are presented in [7-10], do not allow the transition from one coordinate to another at all. Due to the lack of appropriate elements in the structure of these systems, smooth switching of positioning modes is possible. Therefore, we can conclude about the uniqueness of the results obtained by the authors during the modeling.

2. Further research is planned to compensate for the reduction and change the direction of thrust of the propellers due to the interaction of the flow from the rudders with the hull, the impact of the propulsion flow from one engine on neighboring, Coanda effect, for which the authors created with microcontroller control system and satellite navigation system [29].

3. The expected results are consistent with the requirements of the International Maritime Classification Organizations to the CPC SPP of vessels operating in particle board modes. The results of the work can be used in the design and construction of main and auxiliary SPP and control systems of modern ships, in particular – dual-purpose. The use of the results of the study aims to fully create opportunities for solving problems of improvement, reliability, efficiency, security of the CPC SPP, and the implementation of special tasks for the world fleet [30, 31].

4. The social and economic effect of the implementation of the survey results will exceed the costs, as the expected results are aimed at solving the main problems of Ukraine – providing the state with energy resources and improving its defense capabilities.

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