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Research Article

Application of Electromechanical Servo Drive for Control Ship Vendor Propulsor

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ABSTRACT

For such vessels as ferries, tugs, minesweepers, special vessels designed to perform work on the sea shelf, an important indicator is high maneuverability. A unique opportunity to achieve high maneuverability of the vessel is provided by the use of a winged propeller. It essentially performs the functions of a rudder propeller complex, since it combines the advantages of a variable pitch propeller and an active rudder. A vessel equipped with winged propellers can smoothly change speed and direction of movement, turn on the spot, move sideways (i.e., sideways). However, the widespread use of this type of propeller is constrained by the complexity and high cost of both the propeller itself and the hydraulic system used for remote control. The article discusses a method for simplifying the design and manufacture of a winged propeller control system through the use and adaptation of design modules included in the remote control system of the main marine diesel engine.

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1. Introduction

In modern shipbuilding, a wide range of propulsion devices are used to create thrust that ensures the movement of a vessel: fixed-pitch propellers (FPP), variable-pitch propellers (VPP), propellers, water-jet propulsors, rudder propellers, and wing propulsors (Figure 1).

The latter are the most specific type of propulsion, both due to their design and operating principle, and due to their unique capabilities for controlling the vessel's speed and direction. A distinct advantage of the vane propulsion (VP) over any other type of propulsion is its ability to ensure high vessel maneuverability by varying the thrust direction (from 0 to 360°) and its magnitude (from maximum to zero) without changing the main engine's operating mode.

A very significant quality is the ability to regulate the relative pitch during propulsion operation. This is achieved by smoothly changing the angle of attack of the working elements of the wing blades. Consequently, the wing blades can be considered a rudder-propeller system, combining the capabilities of a variable-pitch propeller and an active rudder [1-7].

Figure1. Ship Vendor Propulsor

However, the widespread use of the Ship Vendor Propulsor is constrained by a number of factors. These include, first and foremost, the complexity and high cost of the Ship Vendor Propulsor design. To a significant extent, the overall complexity of its design is due to the need to use a hydraulic control system [8]. This article discusses a simplified method for designing and manufacturing such a system by adapting the structural blocks of the electrohydraulic remote control system (RCS) of the main marine diesel engine to the characteristics of the Ship Vendor Propulsor.

2. Design and Principle of Operation of Ship Vendor Propulsor

The working parts of the Ship Vendor Propulsor that interact with water are vertically positioned wings, the axes of which are fixed on a disk located under the bottom of the vessel (**Figure** 2).

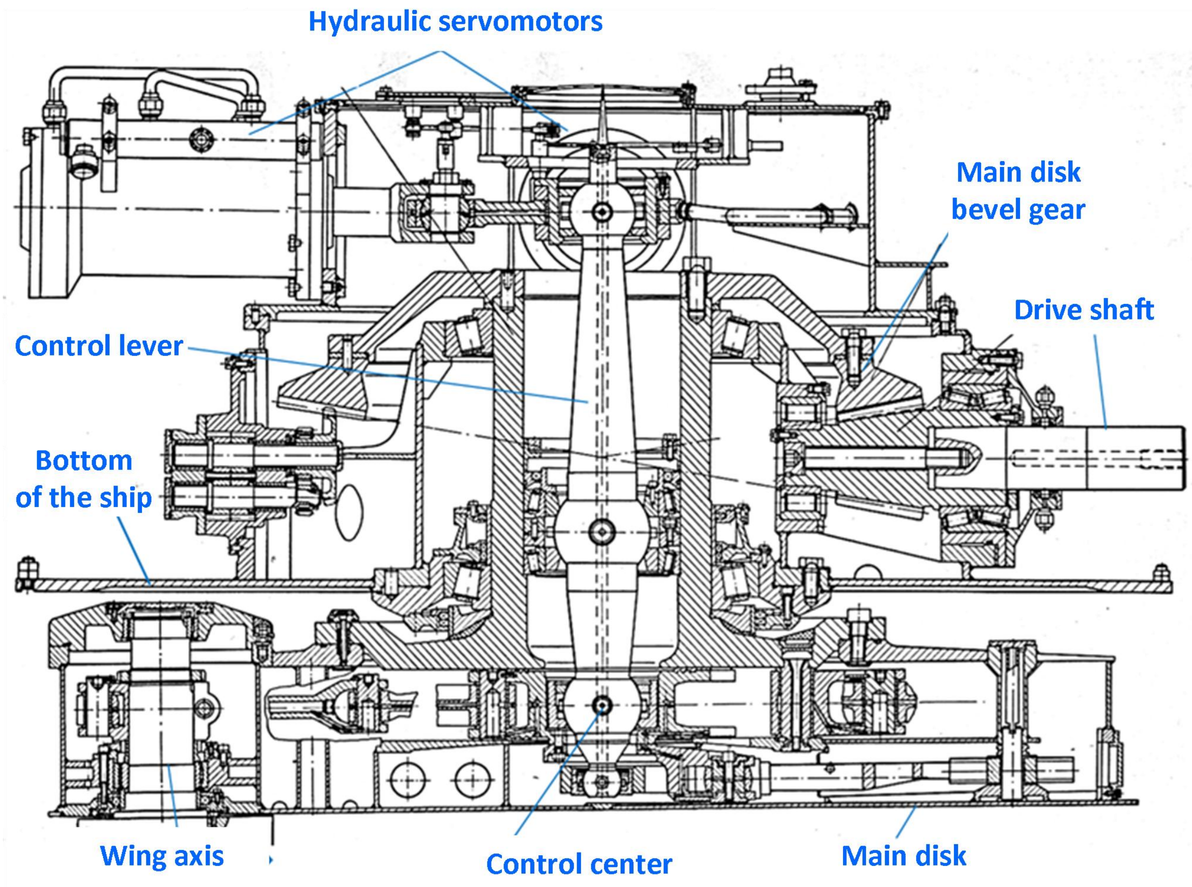

Figure 2. Longitudinal section of the DKK 2000 wing propeller

The disk is driven by a bevel gear connected to the engine (diesel or electric). As the main disk rotates, the wings pivot around their axes using a system of levers connected to a control center. Their pivot angles are determined by the position of the control center. If it coincides with the center of the main disk, all wings are in a neutral position. This eliminates the need for effective hydrodynamic forces and eliminates thrust (Figure 3).

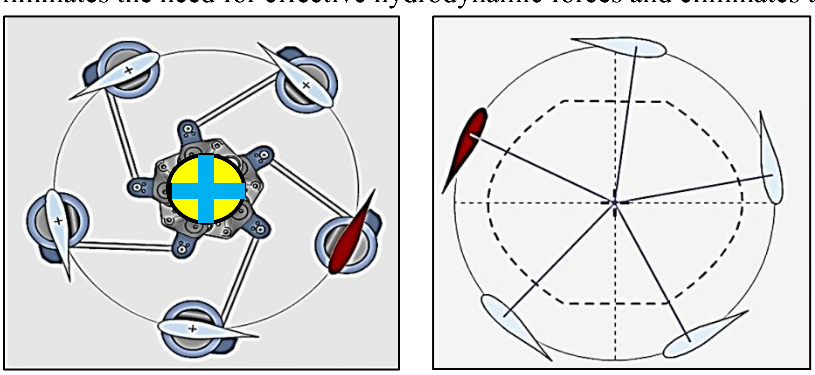

Figure 3. Idle mode

To exit idle mode, it is necessary to shift the control center in the longitudinal or transverse direction, for example, to the right (**Figure** 4).

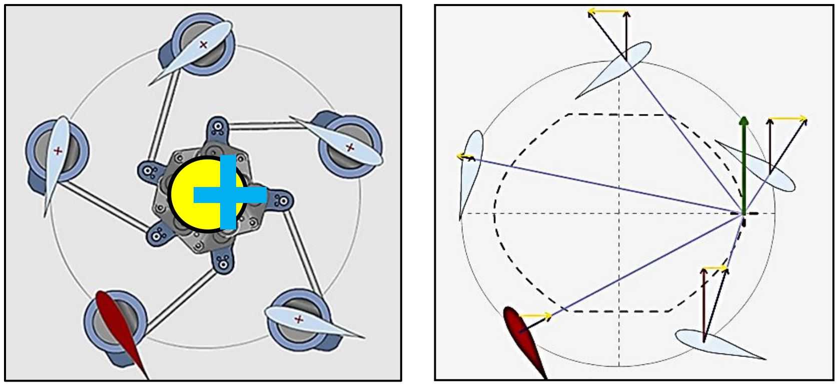

Figure 4. Forward mode

The control center is moved using two hydraulic servomotors that receive commands from the remote control system. (**Figure** 5)

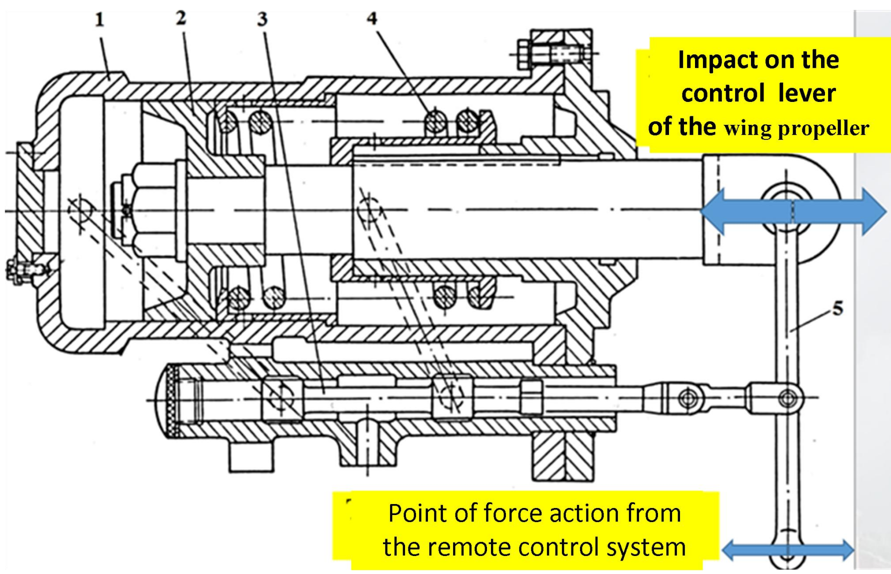

Figure 5. Construction of a hydraulic servomotor

1. Housing 2. Piston 3. Spool 4. Return spring 5. Feedback lever

3. Calculation of the Characteristics of a Propulsion System with a Vane Propeller

3.1 Initial Assumptions

Calculations for vane propellers are typically based on model tests in cavitation tubes or test tanks. The test results are presented as the following dimensionless characteristics:

- relative gait
$$\lambda_P = \frac{V_P}{U} = \frac{V_P}{\pi n D} \quad (1)$$

- thrust coefficient
$$K_P = \frac{2P}{\rho U^2 F_P} \quad (2)$$

- moment coefficient $$K_M = \frac{2M}{\rho U^2 F_P R} \quad (3)$$

- efficiency $$\eta_P = \frac{PV_P}{M\,\omega} = \frac{K_P}{K_M}\lambda_P \quad (4)$$

Designations in formulas 2.1 ÷ 2.4:

VP — speed of the oncoming water flow, m/s;
U — peripheral speed of the rotor (along the axes of rotation of the blades), m/s;
n — propeller speed, rpm;
D — diameter of the propeller (along the axes of rotation of the blades), m;
l — length of blades, m;
Fp = l • D — hydraulic cross-section of the propeller, m^2;
M —is the moment that must be created to rotate the propeller, n·m;

ρ = 1000 kg/m^3 — density of fresh water;

The dependences of the values of K_P, K_M, and η_P on the relative pitch λ_P are called the action curves of the vane propeller. For the M-type propeller, the action curves are shown in Fig. 6.

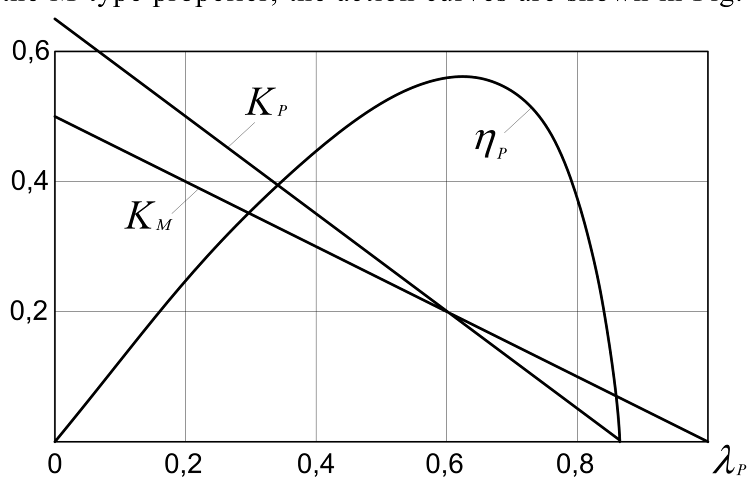

Figure 6. Performance curves of the vane propeller

3.2 Calculation of the Indicators During Free Running of the Vessel

Design parameters of the KD:

n = 20÷100 rpm.

D = 2.6 m.

Number of blades Z = 5.

l = 1.3 m.

Fp = 2.6•1.3 = 3.4 m^2

Eccentricity of the propeller: ε = 0.75

Based on the condition of maximum efficiency of the propeller (see Fig. 6), we select the calculated value of the relative step $\lambda_P = 0.6$ for the nominal movement of the vessel on a free wave.

Table 1. – Calculations for the nominal mode of vessel movement

№	Magnitude	Dimen-sion	Formula	Values				
1	Gait λ_p	-	Set	0,6				
2	k_p	-	From Fig.6	0,2				
3	K_M	-	From Fig.6	0,2				
4	η_p	-	From Fig.6	0,56				
5	rotation speed n	rpm	Set	20	40	60	80	100
6	Peripheral speed U	m/s	$U = \frac{\pi D n}{60}$	2,7	5,4	8,2	10,9	13,6
7	Flow rate V_P	m/s	$V_p = \lambda_p \cdot U$	1,6	3,3	4,9	6,5	8,2
8	Vessel speed V_C	nodes	$V_C = 2{,}05 \cdot V_P$	3,3	6,7	10,0	13,4	16,7
9	Emphasis P	H	$P = \frac{K_P \cdot \rho \cdot U^2 \cdot F_P}{2}$	2503	10012	22528	40049	62577
10	Moment M	N·m	$M = \frac{K_M \cdot \rho \cdot U^2 \cdot F_P \cdot D}{4}$	3254	13016	29289	52064	81351
11	Power N	kW	$N = \frac{M \cdot \pi \cdot n}{30} \cdot 10^{-3}$	6,8	5,5	184	436	852

Table 2. – Calculations for the towing mode of the vessel's movement

№	Magnitude	Dimen-sion	Formula	Values				
1	Gait λ_p	-	Set	0,4				
2	k_p	-	From Fig.6	0,35				
3	K_M	-	From Fig.6	0,3				
4	η_p	-	From Fig.6	0,45				
5	rotation speed n	rpm	Set	20	40	60	80	100
6	Peripheral speed U	m/s	$U = \frac{\pi D n}{60}$	2,7	5,4	8,2	10,9	13,6
7	Flow rate V_P	m/s	$V_p = \lambda_p \cdot U$	1,1	2,2	3,3	4,4	5,4
8	Vessel speed V_C	nodes	$V_C = 2{,}05 \cdot V_P$	2,2	4,5	6,7	8,9	11,2
9	Emphasis P	H	$P = \frac{K_P \cdot \rho \cdot U^2 \cdot F_P}{2}$	4380	17528	39424	70087	109511

10	Moment M	N·m	$M=\frac{K_M\cdot\rho\cdot U^2\cdot F_P\cdot D}{4}$	4881	19524	43930	78097	122027
11	Power N	kW	$N=\frac{M\cdot\pi\cdot n}{30}\cdot 10^{-3}$	10,2	81,7	275,9	653,9	1278

The characteristics obtained as a result of the calculations can be used to evaluate the performance of the vessel and select the parameters of the main engine.

4. Selection of the Design and Structural Modules of the Remote Control System for the Vane Propeller

The typical structure of systems designed for remote automated control of ship machinery and mechanisms includes two main components: a command system and actuators (power) devices.

The input (command) section of most modern automatic control systems is an electrical tracking system. The use of electronic units to generate control signals and process information, and the transmission of signals via an electrical cable, ensures reliability, multifunctionality, low power consumption, and small weight and dimensions of the system units.

The output (power) portion of the automatic propulsion system for all currently known types of vane propulsion units is implemented as hydraulic piston actuators (servomotors). This is explained by a number of their advantages:

- the ability to develop high forces;
- smooth operation of the hydraulic servomotor rod;
- the working fluid—mineral oil, used in marine hydraulic and hydraulic automation systems — provides natural lubrication of rubbing parts and protection from corrosion;
- oil, like any liquid, is virtually incompressible, ensuring the servomotor's characteristics are independent of the forces exerted on its rod.

A distinctive feature of the winged propeller is the need for remote control of two servomotors—the propeller and the steering motor. Therefore, the remote control system must have two control channels for each propeller.

The structure of one of the channels in the electrohydraulic system for remote control of the winged propeller from the wheelhouse is shown in Figure 7.

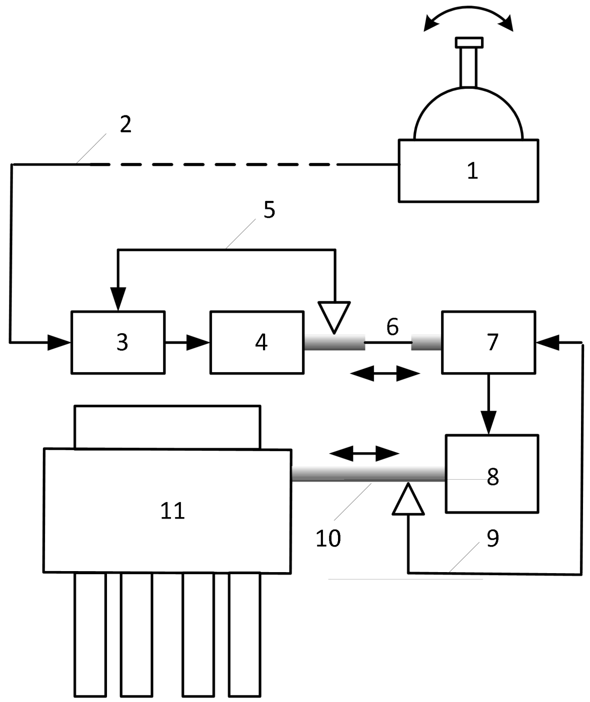

Fig. 7 (left) – Block diagram of the electrohydraulic system for remote control of a vane propeller (single channel)

1 – Control handle in the wheelhouse;
2 – Control electrical signal transmission cable;
3 – Electronic control unit;
4 – Electric actuator;
5 – Electrical feedback;
6 – Connection between the electric actuator rod and the spool valve rod;
7 – spool valve;
8 – hydraulic actuator (servomotor);
9 – feedback lever;
10 – servomotor rod;
11 – vane propeller.

In this article, the possibility of using ready-made modules of the electrical system of the Mini-Marex automatic propulsion system produced by the German company Bosch-Rexroth [9] is considered as the command part of the control system of the winged propeller (Figure 8)

Figure 8. The navigator's console and the command unit of the Mini-Marex remote automatic control system

The system is designed for remote control of twin-shaft marine propulsion systems with reverse gear transmissions. However, thanks to its servo systems with mechanical actuator output and flexible characteristic adjustments, it can also be adapted to control marine winged propellers. This technical solution will reduce the time and cost of developing and manufacturing the control system and allow the use of mass-produced components manufactured with German precision and quality.

The initial command is set by the mechanical position of the control handle. The angular position of the handle is converted into an electrical signal by a precision potentiometer mounted in the control body (see Fig. 8). The end result of the system's command section is a mechanical action on the valve stem of the KD hydraulic servomotor. Therefore, the command section of the DAU system is essentially an electromechanical servo line (Figure 9).

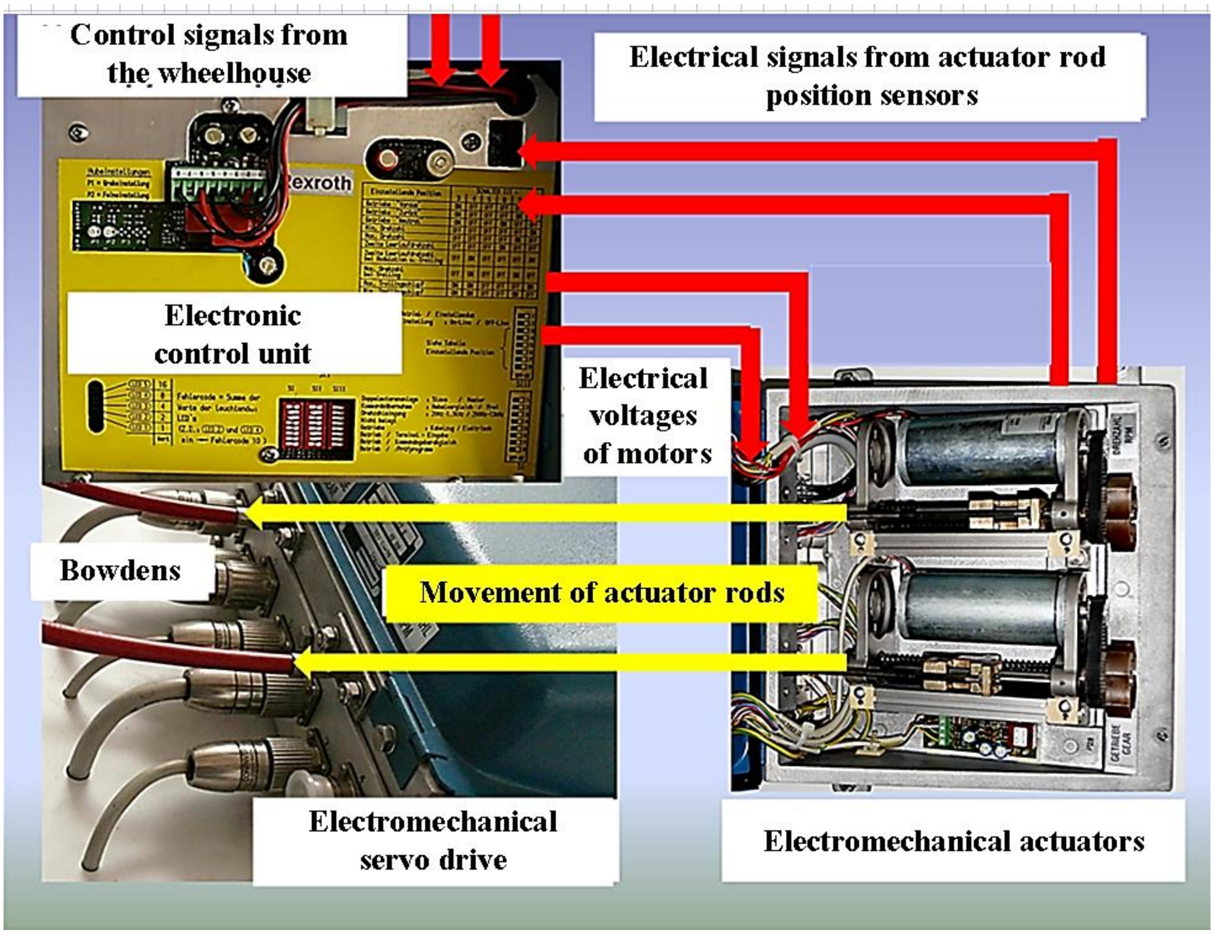

Figure 9. Functional diagram of the electromechanical tracking system

Electrical control signals from two controls located on the navigator's console in the wheelhouse are transmitted via electrical cables to the electronic control unit of the dual electromechanical servo drive, mounted near the controlled object (in this case, near the propeller). The electronic unit generates voltages supplied to the actuators located within the servo drive. These actuators are electric motors whose rotation is converted into linear piston rod movements by means of screw-and-nut kinematic pairs. The piston rod movements are converted by feedback sensors into electrical signals sent to the electronic control unit. There, they are compared with the control signals received from the wheelhouse, and the voltages supplied to the actuator motors are determined based on the difference. This arrangement ensures precise correspondence between the linear piston rod movements and the angular positions of the control handles.

It should be noted, however, that the Mini-Marex DAU system is designed to control the main marine diesel engine. Therefore, the characteristics of its actuators are as shown in Figure 10.

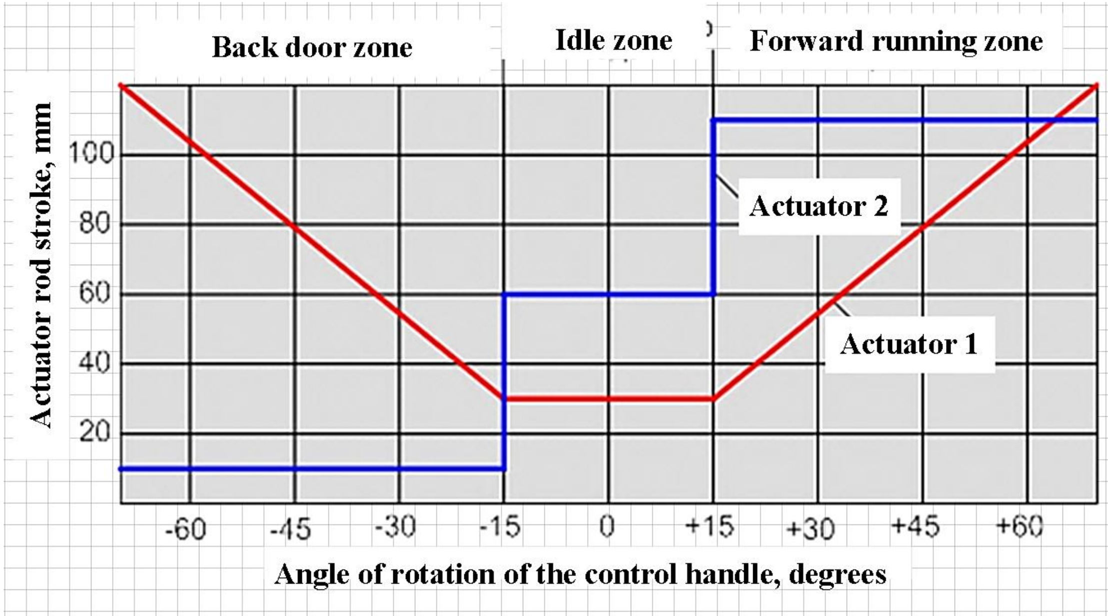

Figure 10. Characteristics of the actuators of the Mini-Marex DAU system
Actuator 1 acts on the diesel engine speed regulator
Actuator 2 acts on the gearbox reverse clutch

The characteristics of the actuators of the vane propeller control system should have the form shown in Fig. 11.

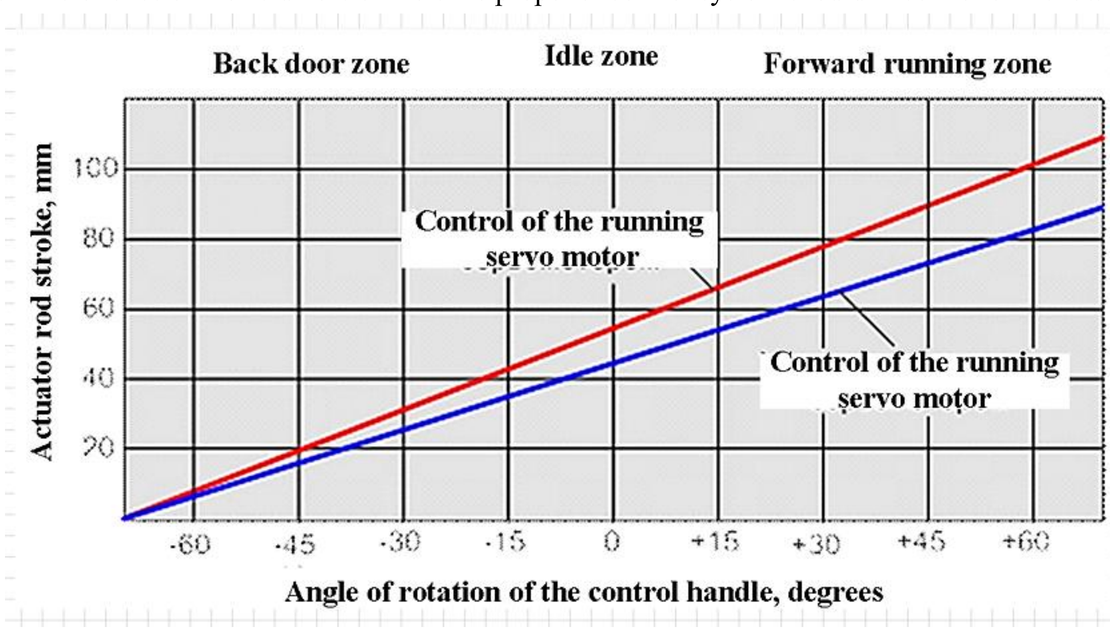

Figure 11. Characteristics of the actuators of the vane propeller control system

Linear movements of the actuator rods of the electromechanical servo drive are transmitted to the controlled object (in our case, to the spool rods of the hydraulic servo drives of the vane propeller) using special devices called Bowdens. These are flexible tubes made of tightly wound steel wire, covered with a protective sheath of oil-resistant plastic. Inside the tube is a 1.2 mm thick elastic steel wire, which transmits the linear movement.

Computer modeling of a propulsion system with a vane propeller and the proposed remote control system demonstrated the possibility of implementing several vessel propulsion modes:

- When the servomotor of the KD is moved transversely, the vessel moves forward or backward in a straight line, changing speed from zero to maximum.
- When the steering servomotor of the KD is moved longitudinally, a thrust is created perpendicular to the vessel's centerline. If the wing propulsors are located at the stern, the vessel will turn in place to the right or left. For a large vessel (e.g., a ferry) with wing propulsors installed in the bow and stern, a lateral, single-directional thrust allows the vessel to move broadside (sideways), which is very convenient when mooring the vessel to the quay wall.

When both servomotors of the KD are simultaneously moved, a thrust is created at an acute angle to the centerline. This ensures circulation mode (movement of the vessel in a circle) in various directions: forward-left, forward-right, backward-left, backward-right.

5. Conclusion

In 2026, the remarkable invention of Austrian engineer Ernst Leo Schneider—the winged propeller—will turn 100 years old. Numerous studies, calculations, tests, and accumulated operational experience, as well as the authors' own calculations, have confirmed this propeller's combination of excellent performance and unique capabilities for accommodating any complex vessel maneuver.

Thaks to these features, the winglet propulsor has found application on ferries, tugs, minesweepers, and floating cranes. For vessels designed for offshore operations, the unique characteristics of the winglet propulsor can be useful for precise positioning. However, the main drawback hindering the widespread use of winglet propulsors is the complexity and high cost of both the winglet propulsion mechanism and the electrohydraulic system required for remote control of its modes.

Thestudies carried out by the authors have demonstrated the possibility of significantly simplifying the design and manufacture of this system by using and adapting the design modules of the DAU system, designed to control the main ship engine

Author's Contributions

The article was prepared by Alexander Ravin, Professor of the Department of Marine Automation and Measurements at the St. Petersburg State Marine Technical University, Doctor of Engineering Sciences (Russia), and Dang Thanh Dat, Master of Science (Vietnam), also a student in the same department.

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Data Availability

Data supporting reported results can be found in the links to publicly archived datasets analyzed.

Conflicts of Interest

The author has no conflict of interest

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