Power control of the engine operating on the fixed pitch propeller

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Abstract. The analysis of operational and constructive methods for changing the power of the main engine working on a fixed pitch propeller has been carried out. To purposefully change the operating mode of the main engine, additional (special) jet action of water on the propeller blades of a fixed pitch can be used. The physical effect of supplying additional water to the blades and its effect on the effective power of the main engine is explained. The mutual arrangement of the propeller load curves of the characteristic modes of the engine when additional water is supplied to the blades is analysed. The additional modes of operation of the main engine, implemented with the help of an additional jet effect, are determined. Purposeful change in power consumption at a constant speed prevents possible overloading of the main engine in case of deterioration of operating conditions. Of further interest is the assessment of the thermal and mechanical tension of the main engine operating in varying operating conditions.

1. Introduction
As the main engine on transport ships, effective low-speed engines operating on a fixed-pitch propeller (FPP) with variable speed are most prevalent. The performance of the main engine on FPP is determined by the mutual arrangement of propeller load curves and limiting characteristics. The power of the main engine during its work on the propeller curve depends on the external operating conditions and the mode of operation of the propeller. Fixed pitch propellers are characterized by high hydrodynamic performance in the design mode. When the operating conditions change, their efficiency decreases significantly (figure 1), which affects the power consumption of the main engine [1]. Operational regulation of the power of the main engine during its operation at the FPP is performed by changing the rotational speed [2]. In this case, the power produced by the main engine is determined by the consumer of mechanical energy - the propeller screw. This pattern forms the dependence of the parameters of thermal and mechanical tension of the engine on the operating conditions and significantly limits the operational envelope of diesel engine [3]. In modern studies, insufficient attention is paid to the ability to change the power of the engine at a constant frequency of rotation of the FPP [3]. There is no analysis of current propeller designs other than the controllable pitch propeller, which allow promptly changing the operating power of the main engine without changing the rotational speed. The design of the controllable pitch propeller allows us to purposefully control the flow around the blades, thereby allowing you to change the power generated by the main engine. Such studies, which allow controlling the flow around a FPP, are represented by passive flow control [4, 5]. It should be noted that to control the ambient flow in the adjacent area - aerodynamics, jetting of additional medium is successfully used
in order to change the mode of operation of the blade devices. Insufficient attention is paid to the possibility of the jet impact of water supplied through the slotted nozzles of the blades on the FPP operating mode and the main engine working on it. This is evidenced by the lack of publications on possible areas of research and the use of these results.

The supply of additional water to the suction surface of the propeller blade in the vicinity of the inlet edge allows changing the flow parameters of the fluid flowing around the surface. This allows to change the nature of the interaction of the blade with water, depending on the parameters of the supplied water. Due to this, it is possible to change the hydrodynamic parameters of the propeller (such as torque, power consumption, efficiency), regardless of the speed and operating conditions [6]. By changing the power consumption and the hydrodynamic moment of resistance to rotation, the required thermal performance of the main engine without overload is ensured.

The aim of the paper is to assess the possibility of changing the mode of operation and the power of the main engine working on a propeller of a fixed pitch, by jetting water through the slotted nozzles of the blades.

2. Methods and materials
The paper discusses the main propulsion plant of a transport vessel, in which the low-speed diesel engine works on a FPP through direct transmission. The mode of operation of the main engine on the FPP is determined by the propeller load curves. The mutual arrangement of the propeller curves of the engine load (figure 2) is formed depending on the design features and the technical condition of the propeller and the hull, the mode of operation of the vessel, the sailing conditions (changes in draft, depth under the keel, weather conditions).

With an increase in the power required to maintain a given rotational speed, the propeller curve becomes “heavier” (see figure 2 Line 2 with respect to line 1), while decreasing it becomes “lighter”. The nominal or design condition curve is the line passing through the point corresponding to the nominal power and the nominal speed of rotation.

3. Results
Methods to ensure maximum compliance propeller main engine by controlling power consumption can be divided into operational and design.

Let us analyse the most common operational and constructive methods for managing the operational
power of the main engine operating on FPP. Currently, the governor is used to change the operational power of the engine operating on FPP. Power control is provided by varying the rotational speed by regulating the cyclic fuel supply. Regulation of the operating modes of the main engine is carried out by adjusting the speed governor. Under operating conditions, it is difficult to change the settings of the speed governor depending on the mode of operation of the propeller, hydro meteorological factors and characteristics of the vessel.

MAN B&W provides changes in the power of the main engine by reconfiguring the timing valve mechanism, optimizing the gas turbine charger and adjusting the fuel supply. Additional matching of the engine and FPP is performed by changing the pitch ratio (P/D): for a lightly load propeller - P/D increases, and for a heavily load propeller - P/D decreases.

Most of the methods for controlling the operating power of the main engine affect the thermodynamic processes in the engine [7]. The power control of the main propulsion plant according to the parameters of the FPP is possible only by changing the geometrical parameters. There is no possibility of reversible and rapid adjustment of the parameters of the propeller.

Analysis of the scientific literature and patent developments showed a significant interest of researchers to the design of the propeller. However, most of the proposed designs have a permanent, unregulated effect on the main engine and cannot be used to control its power. To ensure quality matching of the engine and the propeller during the entire life cycle of the vessel, it is possible to use power control of the main engine under operating conditions:

- screw with discrete pitch;
- toroidal propeller based on Mobius strip;
- propeller for free-swinging blades;
- propeller with additional jet effect of water on the blades [8].

Most of the investigated designs of propellers, proposed for controlling engine power, have signs characteristic of the controllable pitch propeller - movable mounting of working surfaces.

The installation of a slit nozzle [9] on the fixed blades of the FPP (see figure 3) and the jet supply of additional water through it allows to realize the effect on the fluid flow interacting with the blades. Inkjet supply of additional fluid leads to a decrease in the heterogeneity of local speeds on the propeller blades and the flow of the blade. When this happens, the absolute increment of the flow velocity over the entire plane of the suction (sucking) surface of the blade. Additionally, a reduction in the influence of the incident flow, depending on the hull of the vessel, on the mode of operation of the propeller is achieved. There is a decrease in the effect of cavitation on the mode of operation of the propeller and an increase in the cavitation margin.

The obtained effect was confirmed by numerical simulation of the interaction of the propeller and the incident flow in the complex computational fluid dynamic of FlowVision, as well as experimental research of propellers equipped with a slit nozzle in the hydrodynamic pipe [10].

The use of jet impact has a positive effect on the dynamics of the propeller [9], which allows to improve its coefficients for open water diagram. In work [10], the optimal parameters of water supply to the propeller were found, at which an increase in the efficiency of the FPP allowed us to reduce the input (consumed) power by 10% at a constant speed of the vessel. Due to the targeted change in the parameters of the water supplied at a constant rotational speed, the power consumed by the propeller is regulated. Let us analyse the change in the relative position of the propeller load curves of the main engine relative to the nominal propeller curve under the influence of an additional jet effect.

4. Discussion
The analysis of the change in the relative position of the propeller load curves relative to the nominal operating mode is made for 10% of the “sea margin” of power and under the influence of additional jet action of water on the propeller blades.
Figure 4 shows in logarithmic scales the mutual arrangement of the propeller load curves for optimal operating conditions of the main engine, and additional water supply to the FPP blades. Let us analyse the propeller load curves of the typical modes of operation of the main engine in changing sailing conditions (see figure 4). Vessel operation “in ballast”, during transfer to the port of loading, under favourable weather conditions - line 3. When transitioning “in load” and favourable weather conditions - line 2, with deterioration of hydro meteorological factors - line 4. During operation of the vessel and towing resistance (due to fouling of the hull of the vessel) mode of operation of the vessel “in ballast”, when the vessel is transferred to the port of loading, under favourable weather conditions - line 5. When the vessel is "loaded" and favourable weather conditions - line 1 (corresponds to with a nominal propeller curve with a reduced "sea margin"), with the deterioration of hydro meteorological factors - line 6.

Figure 3. The arrangement of the slit nozzle on the propeller: \( V_{\text{flow}} \) - is the free-stream velocity vector; \( V_{\text{jet}} \) - the velocity vector of the additional jet action of the supplied water; 1 - hub; 2 - blade profile; 3 - slit nozzle; 4 – blade.

Figure 4. Propeller load curves of typical operating modes at 10% of the “sea margin” of engine power, working on a propeller, equipped with a slit nozzle for additional jet impact of water on the blades: A – operating mode corresponding to the design speed of the vessel.

When mounted on the propeller blades of the slit nozzles for supplying additional water, the design conditions of operation of the main propulsion plant are preserved. As a result, when the water supply to the slot nozzles is turned off, the propeller load curve of the main engine corresponds to the nominal one - line 1 (see figure 4).

Due to the jet supply of additional water through the slotted nozzles of the blades, the mode of operation of the propeller and the power consumption are changed. By purposefully changing the power consumption by 10%, additional modes of operation of the main engine were obtained. The indicator of the change in the propeller curve (“heavy running”, “light running”) for additional modes (shown in Figure 4) is given relative to the mode of operation without supplying additional water. Figure 4 shows the propeller curves of additional modes of operation of the main engine: 3’ is a heavy running propeller curve under favourable weather conditions “in ballast”; 4’ - light running propeller curve “in load” under adverse operating conditions; 5’ is a light running propeller curve “in ballast” with significant fouling of the hull of the vessel and favourable weather conditions; 6’ is a light running propeller curve “in load” with significant fouling of the ship’s hull and adverse weather conditions.

Analysis of propeller load curves shown in figure 4 allows making recommendations on the choice of operating modes of the main engine. During the operation of the main propulsion plant of the vessel in the initial period of operation or in the ballast, due to the jet water supply, the engine is not overloaded by speed. In case of unfavourable changes in the external operating conditions, the increase in power...
consumption is compensated by the jet supply of additional water to the FPP blade. Regulation of the power of the main engine at a constant frequency of rotation FPP ensures the rational use of nominal power in most operating modes.

5. Conclusion
The analysis confirmed the inability to promptly and reversibly adjust the parameters of the FPP for controlling the power of the main engine. In most of the options considered for controlling the power consumed by the propeller, a change in the position of the propeller blade relative to the incoming flow the controllable pitch propeller is used. Existing methods of controlling the flow of the FPP have an uncontrolled (irreversible) effect on the main engine and cannot be used to control the power.

A method is proposed for controlling the operating mode of the main engine and its power, by changing the parameters of the flow around the propeller, which has become widespread in the adjacent field of aerodynamics. The jet effect of water supplied through a slit nozzle on the propeller blades is used to control the power consumption without affecting the thermodynamic processes in the engine.

The main modes of operation of the main engine are analysed and recommendations for additional modes of operation are developed, we form by means of a targeted change in the parameters of the additional water supplied. In case of adverse changes in the external conditions (factors) of the main engine of the transport vessel, a targeted reduction of power consumption is recommended by proportional increase in the parameters of additional water supplied to the slotted nozzles of the propeller blades.

Due to the use of jet impact of water on the propeller blades, such additional operating modes of the main engine can be obtained, such as:

- heavy running propeller curve under favourable weather conditions in the ballast;
- light running propeller curve “in load” under adverse operating conditions;
- light running propeller curve “in ballast” with significant fouling of the hull of the vessel and favourable weather conditions;
- light running propeller curve “in load” with significant fouling of the hull of the vessel and adverse weather conditions.

On the basis of the obtained results, it is of interest to further study the effect of controlling the power of the main engine, with a constant rotation frequency on the thermal and mechanical tension of the main engine, as well as the rationality of choosing the rated power of the main engine. Also of interest is the study of the joint operation of the engine speed governor and the system of the additional jet effect of water on the propeller blades in transient operating conditions of the main propulsion plant.

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