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ENHANCING THE ENERGY EFFICIENCY OF MARINE FISHING VESSELS

ПІДВИЩЕННЯ ЕНЕРГОЕФЕКТИВНОСТІ МОРСЬКИХ СУДЕН РИБОДОБУВНОЇ ІНДУСТРІЇ

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Abstract. *During each voyage, the vessel's traction capacity decreases due to the gradual degradation of the characteristics of the propulsion complex. This process is influenced by factors such as fouling of the vessel's hull and propeller, a decrease in the power of the main engine due to wear of the cylinder-piston group and fuel equipment elements. All this leads to a deterioration in the traction and speed parameters of the trawler, which, in particular, is manifested in a decrease in the towing speed of the trawls used in the fishing process.*

Trawl modernization can be carried out in various directions. The most famous is the method of changing the design of the trawl's mooring part, including reducing the linear dimensions of the layers and replacing some areas with a fine mesh with larger cells. Such improvements contribute to a decrease in the hydrodynamic resistance of the fishing trawl. Reducing the height of the roughness elements on the elements of the trawl system can be achieved by using bicomponent threads of trawl ropes instead of threads made of polytetrafluoroethylene. In such threads, the core is made of inexpensive thermoplastic fiber, for example, polypropylene, and their surface is covered with a layer of polytetrafluoroethylene.

In addition, it is possible to integrate a distributed fiber-optic measuring network into the material of a fishing trawl, which consists of a set of individual measuring lines arranged in space according to certain parameters.

Анотація. *Під час кожного рейсу тягова спроможність судна зменшується через поступову деградацію характеристик пропульсивного комплексу. На цей процес впливають такі чинники, як обростання корпусу і гвинта судна, зниження потужності головного двигуна внаслідок зношування циліндропоршневої групи та елементів паливної апаратури. Усе це веде до погіршення тягово-швидкісних параметрів траулера, що, зокрема, проявляється у зниженні швидкості буксирування тралів, які застосовано у процесі промислу.*

Проведення модернізації трала може здійснюватися в різних напрямах. Найбільш відомим є метод зміни конструкції мотенної частини трала, включно зі зменшенням лінійних розмірів пластів і заміною деяких ділянок із дрібною сіткою на більші осередки. Такі вдосконалення сприяють зниженню гідродинамічного опору рибальського тралу. Зменшення висоти елементів шорсткості на елементах тралової системи можливо досягти за рахунок використання бікомпонентних ниток тралових канатів замість ниток з політетрафторетилену. У таких нитках серцевина виготовляється з недорогого термопластичного волокна, наприклад, поліпропілену, а їхня поверхня покривається шаром політетрафторетилену.

Крім того, доцільним э інтегрування у матерыал рибодобувного тралу розподіленої волоконно-оптичної вимірювальної мережі, яка складається з набору окремих вимірювальних ліній, розташованих у просторі згідно з визначеними параметрами.

Keywords: trawl, hydrophobicity, polytetrafluoroethylene, optical fibers
Ключові слова: трал, гідрофобність, політетрафторетилен, оптичні волокна

INTRODUCTION. Throughout the entire service life of fishing vessels, a gradual deterioration of their propulsive performance is observed. During each voyage, the towing capacity of a vessel decreases due to progressive degradation of the propulsion complex. This process is influenced by such factors as hull and propeller fouling, as well as a reduction in main engine power resulting from wear of the cylinder-piston group and fuel injection equipment components. All these factors lead to a decline in the trawler's thrust-speed characteristics, which is particularly manifested in a reduction of trawling speed when towing fishing gear during harvesting operations (fig. 1).

Fig. 1. Fishing vessel with trawl
Рис. 1. Рибодобувне судно з тралом

Under such conditions, masters of fishing vessels are compelled to adopt forced operational decisions regarding modifications of fishing regimes. Among the most critical of these is operating the vessel at the engine's maximum continuous rating, which significantly reduces engine lifetime and increases the risk of technogenic accidents.

LITERATURE ANALYSIS AND PROBLEM STATEMENT. Modernization of trawl systems can be performed in several directions. The most widely known method involves modifying the trawl netting section, including reducing the linear dimensions of net panels and replacing fine-mesh sections with larger mesh sizes. Such improvements contribute to a reduction in hydrodynamic drag of the fishing trawl [1].

It is well established that vessel thrust depends on numerous factors, among which the duration of service, particularly in equatorial regions of the World Ocean, plays a significant role. Under such operating conditions, fishing vessels have often transitioned to smaller trawls designed for less powerful vessels as a means of compensating for reduced thrust by decreasing hydrodynamic resistance. Although this approach yielded positive results, it lacked rigorous scientific substantiation and was primarily based on the empirical experience of vessel masters (fig. 2).

A theoretical approach to trawl design based on the similarity method has been formulated [2]. The most effective is the method of force similarity, which is based on scale relationship equations, including: C_R – force scale; C_a – mesh size scale; C_K – drag coefficient scale; C_ρ – density scale; C_d – twine and rope diameter scale; C_V – velocity scale; C_L – linear scale.

If, under clean hull and propeller conditions, the vessel thrust was P_{p1} and subsequently decreased to P_{p2}, the force scale parameter is determined accordingly:

$$C_R = \frac{P_{p1}}{P_{p2}}.$$

Considering constant operating conditions of the fishing system—such as seawater density ($C_\rho = 1$), trawling speed ($C_V = 1$), and structural parameters (twine diameters and mesh pitch: $C_a = C_d = 1$), the drag coefficient scale (C_K) remains unchanged. This is due to the invariability of the Reynolds number under steady operational conditions, namely fixed trawling speed, twine diameters, and environmental properties [1, 2].

Thus, a reduction in vessel thrust results in a proportional reduction in trawl dimensions according to a power-law relationship. Consequently, modernization of the trawl netting section with adaptation to new operating conditions is considered expedient.

Fig. 2. Trawl on deck
Рис. 2. Трал на палубі

RESEARCH GOALS AND OBJECTIVES. In the current situation, the current scientific and technical task is to develop methods and means of modernizing fishing trawls aimed at reducing their hydrodynamic resistance. The introduction of such methods and means can, in the long term, not only increase the total fish catch, but also positively affect the reduction of the cost of the entire fishery.

METHODS AND MATERIALS. One promising direction of improvement involves the application of the non-wetting (hydrophobic) effect.

The use of nano- and micro-technologies enables the creation of water-repellent surfaces that resist wetting due to specially engineered nanostructures. On hydrophobic coatings, surface friction forces can potentially be significantly reduced.

Various artificial nanostructures are employed to achieve non-wetting effects by liquid droplets. Patent developers and manufacturers of water-repellent materials actively recommend the application of hydrophobic coatings in various scientific and technical domains. Their use in the marine industry is considered particularly promising for reducing frictional resistance and improving operational performance.

Modern marine trawls operate within a Reynolds number range 1 ... 3×10^9, corresponding to a fully turbulent flow regime. This regime is of particular interest to designers, as it is directly related to evaluating the effectiveness and feasibility of water-repellent coatings in trawl systems. From the point of view of the chemical and mechanical properties of hydrophobic materials, the flow structure - regardless of whether it is laminar or turbulent - within the near-wall region adjacent to a water-repellent surface should undergo significant modification. These changes are associated with the anticipated liquid slip effect along the solid boundary. However, experimental studies reported by various authors demonstrate substantial discrepancies and contradictions in estimating the magnitude of this effect. This is due to the following factors.

Due to the extremely small thickness of the turbulent boundary layer and its laminar sublayer, surface roughness begins to significantly influence turbulent flow and frictional resistance even at roughness element heights of approximately 0.8 μm. The diameter of microparticles in hydrophobic coating powders is approximately 1 μm, which may increase frictional resistance compared to a hydrodynamically smooth surface. If the initial roughness of the substrate significantly exceeds 1 μm, the micropowder may smooth the surface, resulting in reduced frictional resistance. However, in such cases, the reduction is attributed not to hydrophobic properties per se, but to a decrease in roughness height [3 - 8].

A reduction in roughness elements on trawl system components can be achieved by employing bicomponent twines in trawl ropes instead of pure polytetrafluoroethylene (PTFE) filaments. In such twines, the core is manufactured from an inexpensive thermoplastic fiber, such as polypropylene, while the surface is coated with a PTFE layer.

As shown in Table 1, the surface of an uncoated polypropylene film is characterized by smoothness with an average roughness of approximately 9 nm.

Table 1 - Change in film roughness at different stages of PTFE coating application

Type of PP film with PTFE coating	Uncoated PP film	Unoriented PP film with PTFE coating	PP film with PTFE coating oriented at 118 ... 125 °C	PP film with PTFE coating oriented at 155 °C
Average roughness, nm	9	120	50	9

After PTFE suspension coating, the modified non-oriented film exhibits an average roughness of approximately 120 nm and a granular surface structure. The average grain diameter of the coating (200 … 300 nm) corresponds to the particle size declared by the manufacturer (60 … 400 nm), indicating that PTFE suspension particles coalesce on the polypropylene substrate to form a uniform coating.

During orientation drawing, the coating surface becomes smoothed and leveled. The degree of roughness of the oriented film largely depends on the drawing temperature. At standard temperatures for oriented polypropylene fiber production (118 … 125°C), roughness decreases to approximately 50 nm. At a higher drawing temperature of 155°C, the roughness decreases to the level of the original film (approximately 9 nm).

Modification of the chemical structure and surface topography of the twine through PTFE coatings inevitably affects its tribological properties. It has been established that modifying polypropylene twine with PTFE suspension reduces the friction coefficient from 0.2 to 0.04, approaching that of PTFE (Table 2) [9, 10].

Table 2 - Comparative characteristics of PP twine with PTFE coating, Polifen® та Ftorlon®

Types of twine	Density, g/cm^3	Specific breaking load, MPa	Relative elongation at break, %	Chemical resistance	Friction coefficient
PP with PTFE coating	0,9	630 ± 61	45,4 ± 4,4	Ultra-high	0,04
Polifen®	2,2	100 ... 180	20 ... 40	Ultra-high	0,04
Ftorlon®	2,1	300 ... 600	8 ... 25	Ultra-high	0,04

As a result of modification, the mechanical strength characteristics of polypropylene twine are significantly improved. The maximum strength increase of 59% is achieved at the highest orientation drawing temperature of 155°C. Further enhancement of mechanical properties is possible by increasing the draw ratio and modifying the degree of macromolecular orientation of the thermoplastic polymer. Increased drawing temperature reduces intermolecular interaction within the fiber-forming polymer, enabling the production of twines with a higher level of molecular orientation, ordered structure, and enhanced strength.

Retention of strength in modified polypropylene twine under exposure to chemically aggressive liquids indicates the high efficiency of the protective PTFE coating, which completely covers the surface. The absence of structural defects confirms coating reliability. Increased strength after exposure to aggressive liquids is likely associated with the removal of weakly bonded microparticles from the surface, resulting in improved coating morphology [10].

However, improving the energy efficiency of fishing vessels cannot be limited solely to enhancing the physical and mechanical properties of trawl systems. Effective monitoring of trawl system condition and fishing processes requires an automated control system. Each tier of the trawl system should be equipped with a set of sensors monitoring loads, surface condition of trawl segments, environmental parameters, and providing control of power actuators. Additionally, the trawl system must be equipped with communication lines for transmitting sensor data to data acquisition and processing units. Considering the trawl system length of approximately 150 … 200 m, the use of conventional sensors and non-ferrous metal conductors significantly increases equipment weight and cost.

One promising solution is the application of sensors with integral sensitivity combined into a distributed measurement network. The most efficient technical solution for implementing such systems is fiber-optic technology, as it integrates the functions of an information transmission channel and a sensing transducer within a single measurement path. This enables the development of advanced high-speed measuring devices integrated into complex information-measurement systems for monitoring multidimensional physical field distributions. In general, a distributed fiber-optic measurement network consists of multiple measurement lines spatially arranged according to specified parameters. An integrating fiber-optic measurement line functions as a transducer capable of registering external воздействия along its entire length. To reduce the number of data transmission channels, tomographic methods are recommended, allowing formation of an integral image of the physical field distribution for each measurement line. Even with an incomplete set of integral projections, successful reconstruction of physical field distributions is possible [11 - 19].

The considered technological measures are capable not only of improving the energy efficiency of fishing vessels, but also of elevating the economic performance of the fishing industry to a qualitatively new level. Modified trawl systems can become more efficient, economically advantageous, and profitable compared to conventional designs [20, 21].

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