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Potentiality of Multi-Modular Transformer Watercrafts for Ocean Exploration

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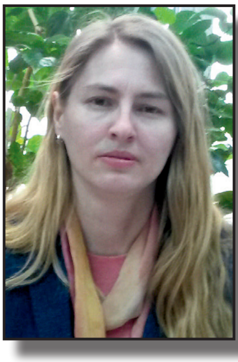

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ABSTRACT

The multi-modular transformer watercrafts based on modules with vortex engines might represent a new class of watercrafts significantly expanding the range of achievable parameters in production processes carried out in the World Ocean.

Composed of modules of the same type and capable of functioning autonomously with vortex propulsion devices, they can, firstly, be assembled to sizes and shapes that are not accessible to modern vessels of traditional design, and secondly, if necessary, they will not have limitations in terms of independent operation, so their properties are similar to artificial islands in any given water area of the Global Ocean, while possessing mobility.

The objective of this paper is to assess the prospects for the use of multi-modular transformer watercrafts as carriers of technological systems for scientific and production processes carried out in the World Ocean.

Models of application of multi-modular transformer watercrafts with vortex propulsion are suggested for their autonomous year-round continuous operation in given non-freezing waters.

To assess the effectiveness of the use of the proposed transformer watercrafts, a simulation of their operation was carried out, as well as a direct comparison of their specifications with traditional vessels that support operation of scientific and production complexes in the World Ocean. For comparison, the currently known marine complexes are selected that require long-term continuous operation (fish canning floating base; a floating complex for extraction and production of liquefied natural gas).

The paper shows that, in relation to all the considered processes, the proposed multi-modular transformer watercrafts have at least two advantages. Firstly, they make it possible to realize continuous and long-term (determined by direct wear of the main module) functioning of the complex, and secondly, with autonomous functioning of individual modules, the zone of action of the complex as a whole is an area with a characteristic size of hundreds of miles.

Keywords: *World Ocean, maritime transport, transformer multi-modal watercraft, seafood production and processing, bottom metal nodules, production and processing of liquefied natural gas.*

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Background. The multi-modular transformer watercrafts based on modules with vortex engines described in [1] might represent a new class of watercrafts that significantly expanding so the range of achievable parameters in production processes carried out in the World Ocean. In particular, they can provide continuous long-term (for several years) operation of production or scientific and technical complexes in any given non-freezing water area of global oceans and seas with maintenance of the necessary transportation and other types of links with management centers and customers. The prerequisites for such an advantage of transformer watercrafts are that, firstly, at the design stage they can be shaped in the optimal way for a particular production process, and, secondly, they have larger productivity and cost-effectiveness of specialized modules that perform specific production operations as compared with conventional vessels.

Objective. The objective of this paper is focused on a qualitative analysis of the possibilities for improving the scientific and production processes, primarily promising ones, of exploration of the World Ocean, and evaluation of potentiality of the use of multi-modular watercrafts as carriers of technological complexes.

Methods. The authors use general scientific and engineering methods, simulation and modeling.

Results.

1. Complex for fishing and processing of seafood

Exploration of marine biological resources in various fishing areas is one of the areas of exploration of the World Ocean, for which prospects of using vessels with vortex propulsion might be obvious.

Vessels with vortex propellers equipped with fishing trawls practically do not differ in functionality from vessels of a traditional layout and even have an advantage of significantly lower fuel consumption [1].

However, an integrated transformer vessel, which can serve as a floating fish processing base, is of most interest. So, while maintaining the technological equipment of a modern processing floating base, a fishing fleet can comprise a set of module vessels of one and the same type (but possibly of different sizes), which, depending on the tasks performed, can be integrated into a larger vessel or function autonomously.

The traditional fish canning floating plant is a vessel of large displacement (for example, crab-fish canning floating base (CFCFB) Vsevolod Sibirtsev with a displacement of 32 thousand tons), which is served by 1–2 receiving and transportation vessels and by 10–12 fishing vessels, as well as by a bulk vessel (tanker).

Maintaining this approach to fishing and processing of seafood, it is possible to use 2–3 central large modules that perform the functions of a floating plant, around the perimeter of which 8–20 small floating modules of the same type that perform fishing and transport functions can be docked (Pic. 1).

The use of vessels with vortex propulsion for the fishing fleet has several obvious advantages. Firstly, we can name easy scalability of the floating plant itself, depending on the zone and season of fishing (i.e., on fish and catch intensity). A floating plant can be formed from a different number of modules (from one to three or even four, more is impractical), which determines total displacement, load capacity, volumes of premises for storing products, areas for placement of technological equipment, etc.

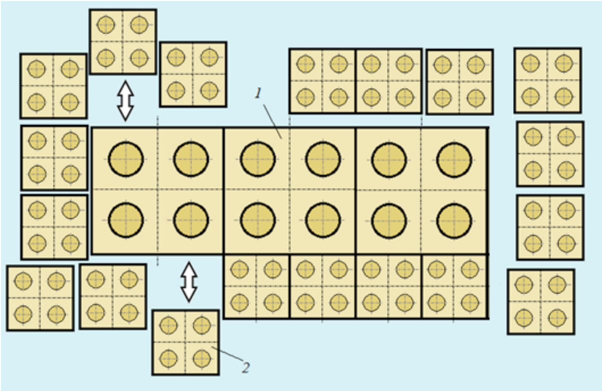
Secondly, traditional floating bases and trawlers consume only about 30 % of fuel for servicing technological equipment (mechanized lines, cold rooms, etc.), the rest is spent on movement. At the same time, vessels with vortex propellers consume 2,5 times less fuel for movement [1]. Comparing fuel consumption of CFCFB Vsevolod Sibirtsev, which is about 5000 tons per raid of 9 months, with a multi-modular complex similar in size and driving properties, it is clear that no more than 2500 tons are needed for independent operation during the year.

Thirdly, lower fuel consumption allows at least doubling of the independent navigation period, unlike the same CFCFB Vsevolod Sibirtsev, which is in the raid for 9 months a year. And with the properly organized logistics of transport modules (performing shipment of finished products, crew rotation, as well as delivery of fuel and other material resources), it is possible to ensure uninterrupted year-round operation of the plant up to complete technological wear-out of the equipment of floating modules.

Table 1

Modelling results

Volume of production per year, t (delivered/stored at floating base)	84800/100	96800/7800	128000/300
Plant workload (based on 22 h/day)	0,47	0,57	0,71
Number of fishing/transport modules	8/4	10/2	12/4
Average load of transport vessels	0,43	0,99	0,65
Average volume of processing per day, t	230	290	350



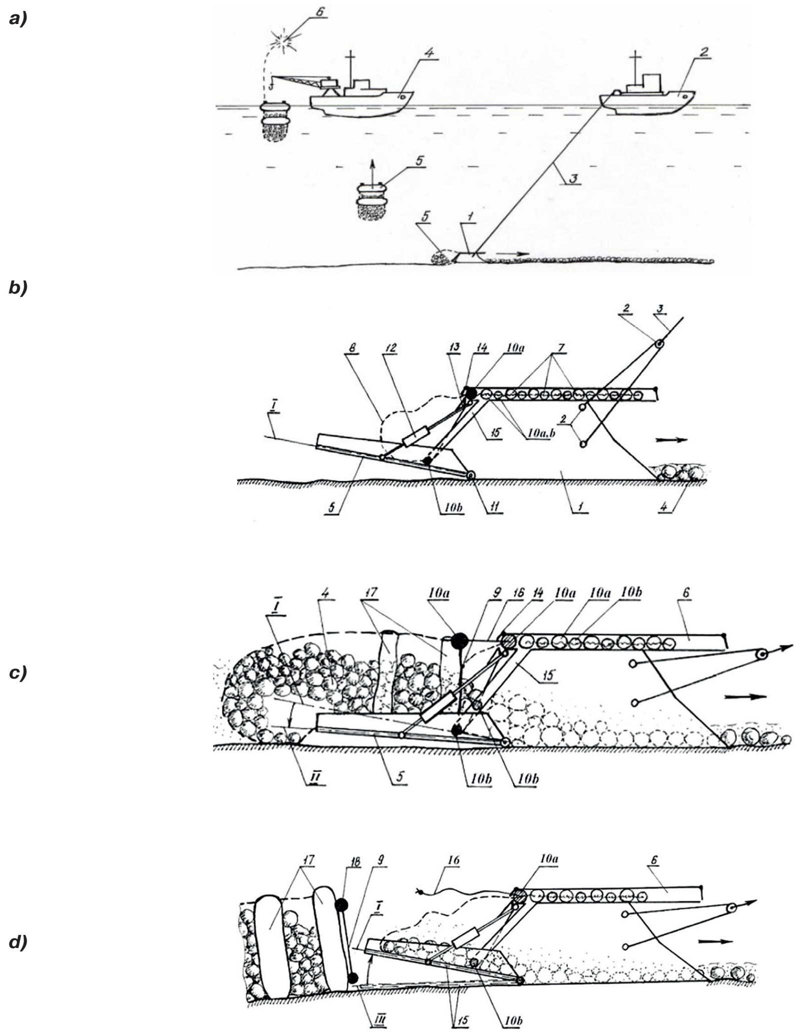
Pic. 1. The implementation scheme of a multi-modular fleet of a fish processing plant: 1 – central module of a floating base; 2 – fishing and transport modules.

To determine the optimal number of modules that form the flotilla of the floating base, a simulation model has been built that allows us to evaluate the production efficiency (volume of output, line load) basing on the fleet composition, that is, considering an estimated catch volume. The system behavior as of a whole depends on a large number of initial parameters, such as the remoteness of the field, the dimensions of the base (the number of modules, load capacity), etc., which are taken into account in the model and are deemed to be controlling parameters.

When constructing the simulation model, it was assumed that fishing seiners are similar in such parameters as displacement, speed, carrying capacity and catch volumes per day to small or medium fishing trawlers and regularly go to shift raids of the same duration, after which the caught seafood goes for processing. Modular transport vessels ship products ashore as soon as their volume permits to fully load them. Shipment time is determined by remoteness of the base from the coast. It is accepted that the main module, which serves as the carrier of technological equipment in a place close to the fishing range, runs at the same distance from the coast. At the same time, the need to follow fish stocks, depending on the zone and fishing season, is not known, and therefore was not considered at this stage. Such an assumption can certainly lead to errors in the results obtained, however, these deviations are not critical and cannot show their general inaccuracy.

Catch volumes are set by a random variable distributed according to the exponential law, with an average catch volume set depending on capacity and power of the fishing trawler module. If necessary, the model can be refined in accordance with the season, fishing intensity and fluctuation of fish stocks [2].

Let us consider the results obtained through modelling the functioning of a transformer vessel, similar in parameters and field of fishing to CFCFB Vsevolod Sibirtsev. The vessel, comparable in size and displacement (225 m long and 80 m wide) consists of three modules with rotors with a radius of 22 m and an interaxial distance of 40 m. The fishing distance is set at 1000 km from the home port. The role of seiners is played by modules with bearing rotors with a diameter of 11 m (with a rated carrying capacity of 200 tons for transport modules and an average catch volume of 100 tons for a trawl module). Table 1 shows product performance indicators depending on the



Pic. 2. Schematic diagrams [3]: (a) development of a nodule deposit by a cassette trawl: 1 – cassette ladle, 2 – towing vessel, 3 – towing cable, 4 – picking vessel, 5 – pop-up trawls, 6 – signaling device, 7 – nodule deposit; (b–d) operation of the cassette trawl: 1 – ladle-bucket, 2 – attachment point for the towing cable, 3 – towing cable, 4 – nodules, 5 – swing plate, 6 – cassettes, 7 – trawls, 8 – high-strength trawl net, 9 – flexible frame of the trawl passage section, 10a – upper roller-holder with a cylinder of compressed air, 10b – lower roller-holder, 11 – hinge of the swing plate, 12 – spring rod, 13 – rigid stop-holder, 14 – spring latch, 15 – inclined part of the cassette, 16 – elastic rope traction halyard, 17 – lifting cylinders- containers, 18 – cylinders with compressed air, I – working position of the plate, II – loading position of the plate.

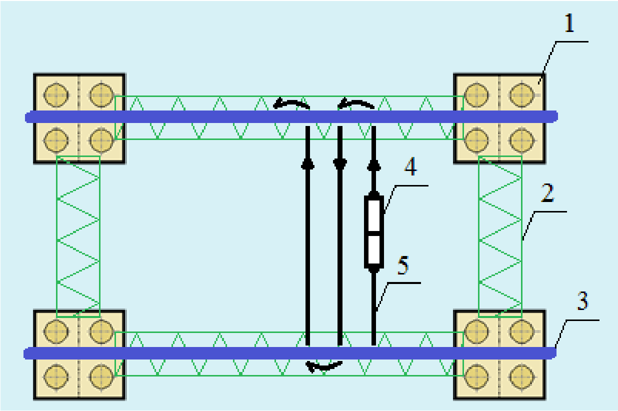
number of modules and their functional distribution.

The table shows that by optimizing the number of supporting vessels, the load of the main processing complex can be increased up to 100 %. The theoretical maximum load of CFCFB Vsevolod Sibirtsev does not exceed 70 %.

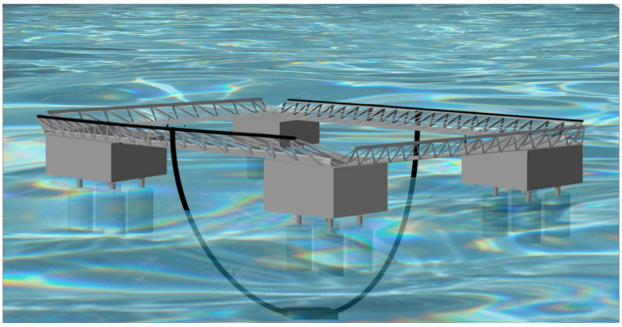
2. Extraction of deep-sea polymetallic nodules

Bottom sediments of polymetallic nodules [3; 4] are currently considered as an important and relatively accessible resource for the metallurgical industry. However, extractive industries do not currently possess well-established technologies for collecting raw materials distributed in a thin layer on the sea (ocean) floor, often at depths of few hundred and thousand meters. Obviously, while a wide variety of nodule deposits can be mentioned [4], it is currently impossible to propose a universal technology for their development.

In [3], a technology was described for collecting and lifting nodules to the surface using the so-called cassette trawl, developed, a)



b)



Pic. 3. The model of the structure of the complex for extraction of deep-sea metal nodules on the basis of a modular transformable watercraft: 1 – supporting modules with winches for moving the trawl, 2 – spacer trusses, 3 – shafts of winches moving the trawl, 4 – twin double-sided trawl, 5 – towing cable.

apparently, for deposits on the low-relief seabed. The essence of the technology and the principle of operation of the cassette trawl are presented in the Pic. 2 reproduced from [3].

It can be seen from the pictures that for any complete extraction of nodules the entire surface of the field must be «scanned» by a towed trawl, which, with a characteristic field size L and width of the trailing part of the trawl l, requires at least $N = L/l$ trawl movements perpendicular to L direction. In terms of the combination of field characteristics and real trawl sizes, the number N cannot be less than 10^3.

Obviously, when towing a trawl with an universal vessel of a traditional layout, the latter must make at least the same number of one-way voyages in order to ensure N movements of the trawl. It is significant that, due to the finite depth of the water area and the inclined orientation of the tow rope, the mileage of the vessel is greater than the distance the trawl moves. In addition, during each voyage of the towing vessel, it must turn in the opposite direction. Finally, the technology under consideration is significantly complicated by the need to strictly combine each new trajectory of the trawl with the previous one.

Thus, the productivity of a single universal vessel at the stage of nodule extraction with a cassette trawl is fundamentally low.

A multi-modular transformer watercraft can be configured to maximize development of a field.

The model of the structure of the technological complex is presented in Pic. 3. The complex contains at least four basic modules located at the vertices of the rectangle with sides along the axes of the modules. The rectangle is located above the developed area of the nodule deposit, the relative position of the modules is fixed by spacer trusses. On two parallel sides of the complex above the spacer trusses shafts of winches moving the trawl are installed.

In the described structure of the complex, it seems advisable to use a twin (double-sided) trawl with two towed cables, as shown in Pic. 3. To transfer such a trawl to the oncoming trajectory, it is enough to shift the pulling cables in the transverse direction (along the shafts of the pulling winches) approximately by the width of the intake part of the trawl.

The described layout of the complex provides extremely complete extraction of nodules from the area covered by the perimeter of the complex with minimal energy consumption, significantly less than when moving a trawl by a single vessel. Indeed, in the latter case, most of the consumed power is spent on moving the vessel itself, which is larger than the trawl by at least an order of magnitude. Accordingly, the effective area perceiving the velocity impact, and hence the power, is 2–3 orders of magnitude greater than the power consumed to move the trawl. In addition, each individual mileage of the towing vessel is always greater than the trajectory of the trawl itself, at least by the length of the tow rope tension.

Optimization of the number of module vessels forming the supports of the mining frame (depending on the perimeter of the scanned bottom surface) and the number of transporting and delivering modules (depending on the remoteness of the field and production volumes) seems to be a very simple task, and the proposed structural model of the complex, which is in its infancy, cannot be specified regarding its functioning by a computer model in the absence of data on the field.

3. Complex for production of liquefied natural gas (LNG)

With depletion and exhaustion of traditional powerful gas fields [5], relevance of developing hard-to-recover reserves (HRR) of gas, in particular, in relatively low-grade but numerous offshore natural gas fields, is constantly growing.

The work [5] describes in detail floating liquefied natural gas platform (Prelude FLNG), designed and built by Royal Dutch Shell corporation to develop a field on the shelf of Western Australia[1]. The project can be considered, in fact, as a modification of a land plant located on a floating base. Currently, it is the largest of the existing floating facilities on Earth (displacement of 600 000 tons). In general, the design of the Prelude FLNG was developed for one specific field based on the conditions of maximum productivity of its exploration and development of this field in the shortest possible period. It is not evident if the fundamental possibility of moving the plant to another field is confirmed by technical characteristics. In particular, the floating base of the plant itself does not have its own propulsion and can only be moved by tugboats. By combination of properties, the LNG floating plant is conditionally mobile and hardly movable to another field.

It is somewhat illogical for a monoblock plant to have systems consisting of a group of identical units operating in parallel (for example, three electric motors, seven Kawasaki marine boilers, six LNG storage tanks, etc.). Such a plant layout assumes besides system redundancy (at least theoretically) that its operation can be executed not at full capacity using only part of the systems that were not implemented in a single copy. When operating in a mode of lower productivity, the inseparable part of the «large» plant, probably might reduce the efficiency indicators of the entire complex.

It follows from the foregoing that while designing an efficient LNG floating plant to develop various fields, it is better not to follow the monoblock scheme.

The multi-modular watercraft proposed in this paper seems to be better option for a floating LNG plant designed for development of various fields, when a change of location is needed.

For direct comparison, the paper proposes a model of the structure of a multi-purpose multi-module transformer watercraft with a total displacement of 600 000 tons, that is, equal to that described in [5; 6], consisting of ten modules of 60 000 tons each. A separate module, which has four bearing rotors with a diameter of 35 m with an interaxial distance of 45–50 m (in the transverse direction) and 60 m (in the longitudinal direction), allows to get a vessel with the length of 515 m, and the width of 170 m.

Depending on the capacity of the field and the optimal required efficiency, LNG plant on a multi-module basis can consist of a different number of modules from a single to a maximum number (in this case, up to ten). When using a single module, the technology is completely analogous to operation of the plant [5; 6]. When using several modules, it is advisable to arrange them along a circuit covering the area of the

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[1] See also https://www.shell.com/about-us/major-projects/prelude-flng.html/ – *Ed. note*.

field so that the entire underwater (bottom) infrastructure is within this circuit.

Some comparative advantages of the plant on adaptable (to the field) floating base consisting of floating modules are obvious. Firstly, the use of a plant (enterprise) of capacity corresponding to the field's capacity eliminates unproductive costs of servicing unused parts of a «large» plant. Secondly, the use of a multi-modular floating base makes it possible to optimize the infrastructure of the underwater (bottom) part of the extracting complex.

It is generally impossible to quantify the reduction in operating costs, but taking the option of a field capacity decreasing from a certain initial value (in the range from 1 to 0) developed by a single floating plant, the cost reduction can be roughly estimated at 50 %.

Conclusions.

1. The paper suggests to use multi-modular transformer watercraft with vortex propulsion for the main areas of exploration of the World Ocean. It is shown that such watercrafts have significant advantages compared to traditional vessels when performing long-term (up to year-round) continuous scientific and technical projects in given water areas.

2. The main performance indicators for complexes based on modular vessels for fishing and processing of seafood, extracting deep-sea polymetallic nodules and LNG have been evaluated. It is shown that in all three considered processes, in comparison with traditional vessels, the specific energy, technological and labor costs are less. Comparison of a relatively obvious set of parameters allows to preliminarily estimate the reduction in transportation costs thanks to the transition from universal to modular vessels at 60–80 %, and labor costs for performing technological operations at no less than 50 %.

3. The indicated advantages of modular watercrafts are due to the optimal composition of the modules, which is determined on the basis of the model of the complex's functioning. In addition, the modular construction principle makes it possible to carry out individual technological operations (fishing and seafood production, transportation of finished products, etc.) by separate specialized modules of relatively low displacement, as well as to ensure the stay of the main technological module, which has a displacement comparable to traditional vessels in a given water area, for almost unlimited time without regular unproductive return to the shore base.

Those conclusions can be specified, improved or complemented depending on further research in that field.

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Editorial comments:

The article now offered to our readers is dedicated to the statement of a sufficiently new problem and seems to be to some extent debatable. The approaches to modelling suggested for deliberation are at the initial stage of explicably general character, but further will certainly require deeper argumentation, and discussion on proposed algorithms and assumptions. Further consideration and detailed substantiation are needed regarding vortex engine, its traction, thrust features, efficiency, possibility to shape the engine in the form of a shell located on the ship's hull, linked to the driving motor. Based on the practices of application of modular principles of construction of complex systems, particularly in naval engineering, one should consider significant constraints of their implementation regarding navigability and seaworthiness, stability, sufficient resistance to flooding, pitching and rolling etc.; strength properties of multi-modular structure under all, comprising extreme, conditions; solution of multicriteria problem when optimization of a parameter may cause considerable deterioration of other parameters, up to complete nonoptimality of the whole design and structure; multiple redundancy of systems and units for secure operation of each module; economic efficiency of multi-modular structure.

At the same time, irrespective of the results of discussion, the statement of those rather new problems might by itself be helpful and initiate the search for efficient relevant solutions. ●