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АНАЛІЗ СУЧАСНОГО СТАНУ ПРОЄКТУВАННЯ СУДЕН ДЛЯ ПІДВОДНИХ РОБІТ ТА УМОВИ ЗАСТОСУВАННЯ ШТУЧНОГО ІНТЕЛЕКТУ

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Анотація: *При вирішенні задачі аналіз сучасного стану проєктування суден підводно-технічного флоту та передумов застосування штучного інтелекту на базі проведеного аналізу сучасного стану проєктування суден підводно-технічного флоту та передумов застосування штучного інтелекту сформульовано наукову проблему з визначенням цілей і завдань подальших досліджень щодо застосування технологій цифровізації та штучного інтелекту в суднобудуванні.*

Ключові слова: *штучний інтелект, проєктування суден, цифровізація судна, судна підводно-технічного флоту, технологічне обладнання.*

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ANALYSIS OF THE CURRENT STATE OF DESIGN OF SUBSEA OPERATION VESSELS AND PREREQUISITE USE OF ARTIFICIAL INTELLIGENCE

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Abstract: *At the research the analysis of the current state of design of subsea operation vessels and prerequisite use of artificial intelligence, on the basis of the current state of design of subsea operation vessels and a prerequisite which is carried out the analysis use of artificial intelligence statement of a scientific problem, with definition of the purposes and problems of further researches of use of technology of digitalization and artificial intelligence in shipbuilding is executed.*

Keywords: *artificial intellect, ship design, vessel digitalization, subsea operation vessel, technology equipment.*

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Introduction. Investigating the analysis of the current state of design of subsea operation vessels and a prerequisite use of artificial intelligence, it is executed the review of traditional and modern design methods of the subsea operation vessels, taking into account features which are carrying out them technological processes. Features are considered and preliminary classification of subsea operation vessels taking into account features of the made analysis and classification of the used technology equipment and apparatus facility is carried out. The review is carried out and probable prospects of researches of digitalization at design of vessels, with opportunities of use of technology of artificial intelligence are considered. On the basis of the conducted researches statement of a scientific problem, with definition of the purposes and problems of further researches of use of technology of digitalization and artificial intelligence in shipbuilding is executed. Research purpose: Analysis of the current state of design of subsea operation vessels and prerequisite use of artificial intelligence.

Classification and features of subsea operation vessels. The operation performed by vessels of the subsea operation fleet mean the sea operations performed at various depth in any point of the World Ocean, with use of technical means. Treat similar operations, all types of working diving operations, building of underwater constructions, an underwater wrecking, research and surveying works and safety of sea borders.

When performing subsea operations, along with the diving equipment, are used, the remotely operation vehicle (ROV) [1], the autonomous underwater vehicles (AUV) [2] and the manned submersibles (MS) [1; 2]. For ensuring successful and safe operation of the listed specialized equipment, reliable vessels of the subsea fleet are necessary [3; 22].

Vessels of the subsea fleet, are classified, on the listed below types and are schematically reflected in fig. 1:

– Subsea Construction Vessels;
– Diving Support Vessels;
– ROV Support Vessels;
– AUV Support Vessels;
– MS Support Vessels.

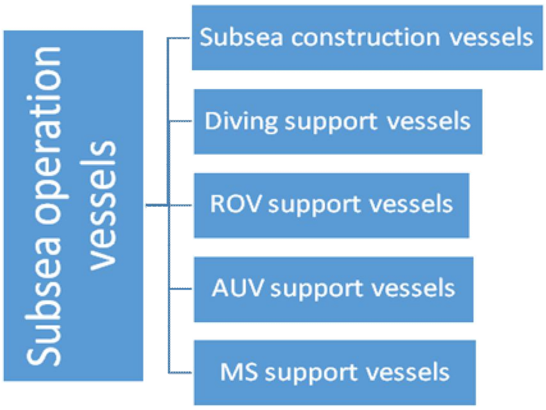

Fig. 1. The block diagram of group of the types of subsea operation vessels

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Considering the description of subsea operation vessels and the publication, it is possible in a certain plan to state positive and negative sides of subsea construction vessels, to rather special subsea operation vessels. Lower in table 1, the comparative analysis of subsea construction vessels with special vessels is reflected.

Table 1

Comparative analysis of subsea construction vessels with special diving vessels and vessels supports of apparatus facility

Subsea construction vessels	**Special diving vessels and vessels supports of apparatus facility**
The operation platform with the deck space	Existence of a stationary diving complex
Existence the universal lifting gears	Existence of a stationary apparatus facility
Subsea cargo crane	Maximum adaptation the installed apparatus facility or diving complex and support vessel
Living space for operation crew	
Possibility of installation of mobile technology equipment, apparatus and diving complexes	Possibility of performance of transitions to any point of the World Ocean for operation on various projects
Flexibility for adaptation to new projects	

Considering the carried-out classification of subsea construction vessels reflected in table 2. Formation of the general classification of subsea operation vessels.

Table 2

Classification of subsea construction vessels on the installed apparatus and complexes

The subsea construction vessel levels	**Installed apparatus and complexes**			
	ROV	**AUV**	**MS**	**Diving complex**
IV level	«M» class	Portable	Shallow water to 200 m	SDS < 12 SDS < 60
III level	Big & Deepwater (Observation) Middle (Worker)	Lite	Shallow water to 200 m Middle depth to 2000 m	SDS < 60 SDS ≥ 60
II level	Deepwater (Observation) Middle & Big (Worker)	Middle	Middle depth to 2000 m	
I level	Big & Deepwater (Worker)	Heavy	Deep water Ultra deep water More 2000 m	

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In process of expansion of development of a sea oil field, the volume of subsea and technical operations will constantly increase. In this regard the researches connected with subsea operation vessels has to proceed, improving this type of vessel and will not lose the relevance.

Review of traditional design methods of subsea operation vessels. Design method of the subsea operation vessels being based on the accepted systems of the order, represents naturally developing process, at the same time design of subsea operation vessels have the feature. Irrespective of type and purpose of the vessel the project is developed on the basis of the universal principles. The general methodology of design of modern vessels are considered in works of many authors [5; 4; 6; 7; 8; 9; 11, etc.], and are accepted as a theoretical basis of this research. In the solution of separate problems of research design use of the computer equipment and software was new.

Thanks to creation of a CAD, there was a possibility of a complete solution of multiple tasks exact mathematical models of design of the vessel, optimizing technical elements by criteria of technical and technological efficiency. Emergence of such software of a CAD how «APA» [https://www.napa.fi/], «CADMATIC» [https://www.cadmatic.com], «AVEVA» [https://www.aveva.com/], «Smart Marine 3D», etc., with the developing specialized modules offer big prospects to optimizing design and automated management of design and vessel construction. Design of the modern vessel as engineering construction, is based on system approach, being organized set of the structural elements interconnected and performing certain functions, the become main methodical basis of creation of mathematical models in a CAD.

System approach, [9] is defined as optimum technical implementation of a plan of creation of the vessel which is an important element in perspective oil and gas projects. Accounting of many factors providing optimization of technical elements of vessels as uniform system the vessel – technology equipment - technological operation that demands development and improvement of the corresponding design methods is reflected in system approach.

In a CAD, considerable development methods of geometrical modeling for obtaining the graphic representation (3D model), the perspective vessel in the course of its design gained. For formation of superficial geometrical model of the vessel, such software as «Free Ship» [https://free-ship-plus.en], «MaxSurf» [https://maxsurf.net/], by «Delft Ship» [https://www.delft-ship.net/] etc. are used today. The listed programs (except «Free Ship»), work in the uniform IGES format with such software as «CADMATIC», «AVEVA», «Smart Marine 3D», «NAPA», etc. that gives the chance at all design stages to perform works in a common information space. the 3D model gives the chance of real assessment of opportunities of the designed vessel and assessment of compatibility of technical and processing equipment. Together with methods of definition of quantitative characteristics of the automated research design also methods of optimization constantly were improved. Along with creation of mathematical models, also the special methodology of work in a CAD is formed, the sequence of performance of 3D models, data structure is developed for calculations, a form of representation of the received results, etc.

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For achievement of the goal of design with use of the CAD tool, the following groups of tasks of the theory of systems have to be consistently solved [9].

1. The description of system objects, their structures for the purpose of realization of system approach in all its aspects [9];
2. The analysis of a system on the basis of the received description [9];
3. The risk estimate;
4. Synthesis of the system.

All listed above tasks are connected with information processing about the designed vessel. For this reason, the designing process can be presented as information process. In general, the theory and methods of research design are constantly improved and their introduction in practice promotes acceleration of scientific and technical progress in shipbuilding.

Analysis and classification of technology equipment and apparatus of the subsea operation vessels. On the subsea operation vessels of the both stationary, and mobile technology equipment is usually used.

Mobile technology equipment

Providing at design of subsea operation vessels, descent - lifting gears, subsea cranes, the cargo deck space and the Moon Pool, in the absence of an opportunity or inexpediency of use of stationary technology equipment, it is possible to use mobile technology equipment. The listed below types of the equipment belong to mobile technology equipment:

- Deepwater modular type diving complex;
- Container type diving complex;
- Container type apparatus facility (ROV/AUV);
- Mobile drilling complex;
- Mobile flexible pipe lay complex;
- Mobile cable lay complex, etc.

Use of mobile technological complexes expands possibilities of subsea operation vessels and turns them into the multi-purpose operation platform capable to carry out a wide range of operation on a sea oil field.

Stationary diving complex

The stationary diving complex established on the special vessels for diving operation supports is intended for performance of subsea operation with carrying out diving immersions. The main criterion of classification of a diving complex by rules of classification societies, is immersion depth. Classification of a stationary vessel diving complex by a class notification symbol, is listed below.

- SDS < 12 – if the vessel is equipped with the vessel diving complex intended for operation of divers at depths less than 12 m.
- SDS < 60 – if the vessel is equipped with the vessel diving complex intended for operation of divers at depths less than 60 m.
- SDS ≥ 60 – if the vessel is equipped with the vessel diving complex intended for operation of divers at depths more than 60 m.

Apparatus facility, ROV & AUV

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Remote operation vehicle is divided by depth, weight, dimensions, power of propulsion, type of the drive and appointment. The standard classification of apparatus still does not exist. Now [1], they can be broken into seven main categories (table 3).

Table 3 [1]

Classification the ROV for category

#	ROV class	Weight, kg	Appointment	Depth, m	Type of the drive	Power, h/p	Price, thou. $
1.	Micro- mini-	<30	Observation	<150	Electrical	<5	to 50
2.	Small	<100	Observation	<600	Electrical	<10	to 100
3.	Big	<300	Observation/ lite operation	<3000	Electrical	<20	to 500
4.	Deep-water	<500	Observation/ data operation	>3000	Electrical	<25	to 1000
5.	Middle	<3500	Lite, middle, heavy operation	<2000	Electrical-hydraulic	<100	to 1000
6.	Big	<15000	Heavy operation, big floating capacity	<3000	Electrical-hydraulic	<300	to 1000
7.	Deep-water	<15000	Heavy operation, big floating capacity	>3000	Electrical-hydraulic	<120	From 1000

Breakdown of AUV on groups is made depending on purpose of the device [2]. Anyway purposes of the device and model of use define its equipment, operating depth, autonomy and mass-dimensional characteristics.

In the master plan of US Navy of UUV Master Plan, 2004, the following classification of «AUV», table 4 is used. [2]:

Table 4 [2]

Classification of AUV by general to the plan of US Navy

AUV class	Hull diameter, mm	Weight, kg	Cruise capacity (at basic loading), h.	Cruise capacity (at maximum loading), h.	Volume the payload, m^3
Portable	80 - 230	from 45	from 10	10 - 20	from 0.25
Lite	324	230	10 – 20	20 – 40	1 – 3
Middle	533	from 1360	20 – 50	40 – 80	4 – 6
Heavy	to 910	9000	100 – 300	to 400	15 – 30

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In other sources (for example, Douglas-Westwood) AUV are classified by the following table 5 parameters [2]: operating depth, length, the distance on the one battery charging.

Table 5 [2]

Classification AUV from Douglas-Westwood

AUV class	Length, m	Weight, kg	Operating depth, m	Distance, km	Price, $
Lite	to 2	to 50	100	20 – 40	to 250
Middle	2 – 3	50 – 500	500 – 3000	40 – 150	250 – 1000
Heavy	3 – 6	500 – 5000	от 1000	150 – 300	1000 – 5000

Manned submersible apparatus MS

Below preliminary classification «MS», for presumable formation of shape of the perspective vessel is shown.

On immersion depth manned submersibles conditionally divide into devices [1, 2]:

- For shallow water – to 200 m;
- For middle depth – to 2000 m;
- Deepwater – more 2000 m.

On design features in separate groups it is possible to allocate devices of the following categories of manned submersibles [1; 2]:

- Bathyscaphe - feature is existence of the float filled with gasoline, are capable to plunge of any depths of the World Ocean, including limit;
- Bathyplane – towing apparat - «the underwater glider» for observations at shallow water;
- Devices with a compartment for an exit of divers in water - are equipped with a hyperbaric compartment for transportation of divers;
- Autonomous deep-water shells - are carried by the equipment for carrying out subsea operations, such as manipulators and compartments for the lifted freights and samples;
- Saving deep-sea submersible (SDS) – are equipped with a passenger compartment, the docking device and the lock-chamber for rescue of crews of submarines.

Digitalization in ship design. *Digitalization in ship design* – this implementation of digital technologies in processes of development of vessels which allow to increase accuracy, to reduce terms and expenses, to optimize operational characteristics. The purpose – full transition to digital technologies at all stages of life cycle of the vessel - from design before utilization.

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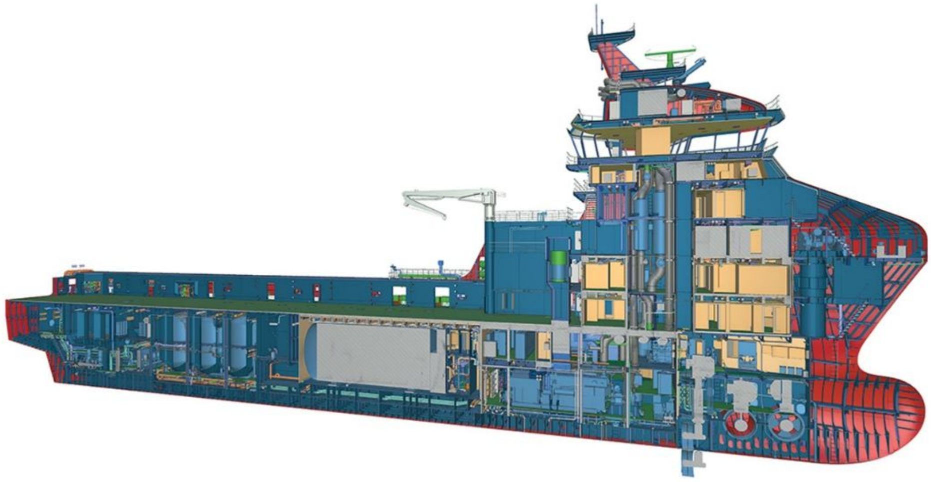

Fig. 2. The vessel 3D model [cadmatic.com]

Some technologies of digitalization in design of vessels:

- *CAD (Computer-Aided Design)* – the computer design allowing to create exact three-dimensional models of vessels, their knots and systems.
- *CAE (Computer-Aided Engineering)* – the engineering analysis including calculations of durability, hydrodynamics, stability, vibrations, heat transfers, etc. Both technologies work in a sheaf: CAD creates model, and CAE - analyzes her behavior in the set conditions. Together they form the digital double of the vessel even before its construction.
- *The constructions 3D-modeling* – exact volume models of the hull, superstructures, mechanisms, pipeline systems, ventilation, propulsion plant, etc. are created.
- *Visualization & simulation* – interactive demonstration of the vessel in the virtual environment: survey of internal rooms, simulation of operation of mechanisms, training of crew.
- *Formation of production documentation* – systems automatically generate the drawings, specifications, reports, maps of cutting of metal given for CNC machines.
- *Transfer of digital model on shipyard* – by means of a PLM system (Product Lifecycle Management) the digital model accompanies the vessel at all stages - from a bookmark before utilization.

For digitalization of design of vessels are used, on an example:

- *Siemens NX* – specialized environment for modeling of concepts of vessels, detailed design and obtaining production information [siemens.com].
- *CADMATIC Marine Design* – the software for shipbuilding, facilitates a designing process at all stages of the project [cadmatic.com].

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– *The shipbuilding digitalization platform* – The platform includes modules for design of hull designs, schematic diagrams of ship systems and pipeline systems.

Use of digital technologies in shipbuilding is regulated. He establishes basic provisions on development and application of computer models of products of shipbuilding and the processes connected with this product at all stages of life cycle.

Some directions of development of digitalization in design of vessels:

– *Creation of the uniform platform of shipbuilding* – The purpose - to create the independent and safe program stack covering all life cycle of an object of marine facilities – from the initial specification and conceptual design before descent to water.
– *Development of technologies of digital duplication and digital doubles of the designed vessel* – it will allow to create the virtual model of the project allowing any changes of various characteristics and displaying the resulting indicators.
– *The production integration* – the digital model can be directly loaded into machines with the numerical program control (CNC), the automated assembly lines, robot's welders that minimizes influence of a human factor and increases production accuracy.

Use of technologies of artificial intelligence in shipbuilding. Technologies of the artificial intelligence (AI) are applied in shipbuilding in different spheres: the ship design, the ship building, operation and safety.

The ship design:

– *The design optimization by means of algorithms of machine learning and deep training.* They analyze large volumes of data, considering a set of parameters, such as hydrodynamic characteristics, energy consumption and durability of materials.

An example:

– *The generation design* – the algorithm creates a set of potential designs, tries forms which the person engineer could not consider because of their not traditional character or complexity. Each generated option is checked for compliance to the set restrictions (durability, weight, etc.):
– *Modeling of behavior of the vessel in extreme weather conditions* – algorithms find constructive solutions which increase stability and reduce rolling amplitude.
– *Acceleration of the cycle «design production»* – automation of routine calculations and optimizing tasks reduces design time from months to weeks.
– Adaptability and customization – «AI» allows to create quickly highly specialized projects under concrete needs of the customer and a concrete route, but not to use average «universal» decisions.

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Shipbuilding:

- Automation and robotization - development of «AI» in shipbuilding leads to creation of robotic systems which operate separate stages and production in general;
- Robotization systems for management of separate stages (metal cut, welding, coloring, quality control of hull works).
- *The system material monitoring & management* – «AI» helps to form the system of monitoring and management of the used materials, to create the integrated information system for digital production.
- *Create the «Digital shipyard»* – «AI» it is used for updating of production structure, reduction of amount of defects and improvement of quality of products.

The shipping operation:

- The automation systems on the basis of «AI» control and operate various functional blocks of the vessel, including navigation, maneuvering, control of engines and the equipment. It increases the accuracy and reliability of ship operations, reduces risk of human mistakes.
- Forecasting of refusals and diagnostics of a condition of the equipment on the basis of «AI» possible problems allow to warn and also to optimize the schedule of maintenance.
- Intellectual systems of support of operation on the basis of «AI» which provide technical readiness and survivability of the fleet. Their basis is made not by(with) documents, but the computer model of an object describing not only a design, but also behavior of technical means in various modes and conditions.
- Virtual exercise machines on the basis of «AI» allow to train crews of vessel in the conditions as close as possible to real that promotes increase in their qualification and safety onboard.

Safety of navigation:

- *Systems for monitoring of a condition of the vessel (an example, HiCBM)* – in real time trace a condition of the capital equipment, including mid-flight engines, compressors and pumps, and warn about possible problems during swimming. Having used «AI» HiCBM, it is capable to find and prevent potential breakages, providing the safe movement of the vessel.
- *The system for provide safety manage the vessel (an example, HiCAMS)* – use on board video cameras for the analysis of the events connected with safety, in real time, increasing the level of protection of the vessel and its team.
- *Systems for prevention of collisions* – for example, the system of forecasting of trajectories which uses data on actions and behavior of personnel of the vessel which is carrying out movement along the same route together with difficult hydrodynamic model of the vessel.

At this AI will not be able fully to replace the engineer – it will only expand space for possible decisions which the expert will be able to choose consciously.

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Statement of a scientific problem. At design of subsea operation vessels, it is necessary to consider requirements imposed to the designed vessel, technology equipment, complexes and apparatus systems.

Formation of the purposes and research problems are reflected in the block diagram, fig. 3.

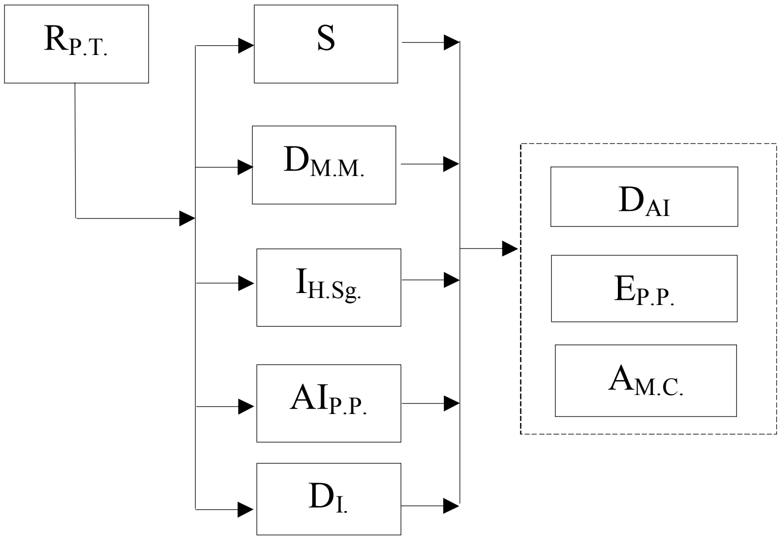

Fig. 3. Block diagram formation purpose and scientific problems

here $R_{P.T.}$ – purpose and scientific problems;
S – system analysis and mathematical models the research objects;
D_{MM} – design process mathematical models;
$I_{H.Sg.}$ – intellectual formations the hull and seagoing parameters analysis;
$AI_{P.P.}$ – formation the propulsion plant with using the «AI»;
D_I – the integration intellectual platform for design;
D_{AI} – formation the design methodology on the «AI» base;
$E_{P.P.}$ – the vessel propulsion plant ecology level improvement;
$A_{M.C.}$ – formation the subsea operation vessels classification models.

Research purpose, include the group reflected in the block diagram of fig. 3. as (D_{AI}, $E_{P.P}$, $A_{M.C}$.), it is described by formula 1., and research problems, include the group reflected in the block diagram of fig. 3., as (S, D_{MM}, $I_{H.Sg.}$, $AI_{P.P.}$, D^I), it is described by function 2.

$$R_T = D_{AI} \bigcup E_{P.P.} \bigcup A_{M.C.} \tag{1}$$

here $R_{T.}$ – purpose of research.

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$$R_P = A_S f(S, D_{MM}, I_{H.Sg.}, AI_{P.P.}, D_I), \tag{2}$$

here $R_{P.}$ – problem of research;

A_S – boundary condition of design of the vessel.

Thus synthesizing expression 1. and 2, we receive mathematical model of the expected research described by formula 3.

$$R_P = A_S f(S, D_{MM}, I_{H.Sg.}, AI_{P.P.}, D_I) \in \tag{3}$$

It is as a result supposed to consider influence of the systematized research problems, on formation of research purpose, such as formation of methodology of design on the basis of artificial intelligence, increase in ecological level of the vessel propulsion plant and formation of classification model of subsea operation vessels.

Conclusion

As part of this study, based on a review of traditional and modern design methods and taking into account the specific characteristics of the underwater technical fleet, the distinctive features of these vessels have been examined and a preliminary classification has been carried out, taking into account the findings of the analysis and the classification of the technological equipment and hardware used. An overview has been carried out and the likely prospects for research into digitalisation in ship design have been examined, including the potential for applying artificial intelligence technology. A research problem has been formulated, defining the aims and objectives of further research into the application of digitalisation and artificial intelligence technologies in shipbuilding.

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