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IMPROVING THE DESIGNING OF MARINE TETHERED SYSTEMS USING THE PRINCIPLES OF SHIPBUILDING 4.0

V. Blintsov
Doctor of Technical Sciences, Professor
Department of Electronic Engineering of Ship and Robotic Complexes*
E-mail: volodymyr.blintsov@nuos.edu.ua
K. Trunin
PhD, Associate Professor
Department of Management*
E-mail: trunin.konstantin.stanislav@gmail.com
*Admiral Makarov National University of Shipbuilding
Heroiv Ukrainy ave., 9, Mykolayiv, Ukraine, 54025

This paper considers the issues and theoretical aspects related to improving the design of maritime tethered systems (MTSs) with flexible links (FLs) using underwater towed systems (UTSs) as an example. That allows them to be used in the early stages of design by implementing the principles of Shipbuilding 4.0 and BIM technologies. Such regimes have not previously been described by existing mathematical models (MMs). The expected result of the current study is a significant decrease in the cost of different resources. At the same time, the basic reliable results of design solutions could be obtained already in the early stages of design.

The theoretical basis of the proposed method for improving the design of MTS with FL is the improved design concept (IDC) for MTS with FL while the tool base of the method is a special modeling complex (SMC). The use of IDC along with SMC at the research (pre-prototype) design phase reduces the number of MTS design stages.

The proposed method to improve the design of MTS with FL, based on the MM that notates the dynamics of MTS FL and MTS with FL, makes it possible to investigate different modes of operation of almost all MTS classes. That allows devising the recommendations for predicting possible operational loads in order to design their elements. At the same time, there is an opportunity to improve the existing methods for calculating and designing MTS with FL with the required properties and parameters, and to bring them to the level of engineering application.

The application of SMC at the pre-prototype design stage makes it possible to avoid the use of physical modeling of the operational regimes of MTS with FL associated with the full-scale testing on the high seas

Keywords: MTS design improvement, Shipbuilding 4.0, BIM Technology

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1. Introduction

It is expected that the introduction of the Shipbuilding 4.0 principles in the shipbuilding industry brings the future closer, creating new values and putting forward new requirements to reduce production and operating costs while improving production efficiency. Shipbuilding 4.0 (Seafaring 4.0, Shipbuilding Production 4.0, etc.), based on the principles of Industry 4.0, should change production systems, operation, navigation, design, logistics, and service delivery, thereby creating value in all aspects of the shipbuilding industry. Over the next decade, manufacturers will follow the course of transferring production from outdated plants of the past to a data-rich, optimized, and efficient future of the "smart" plant. The key to this transformation is the data to generate a synchronized flow of digital information that connects even the most disparate global supply chains into a single digital enterprise. A transition to the concept of production and maintenance of a product (project) throughout the life cycle is underway.

The idea of using the Shipbuilding 4.0 concept is to digitize the results of designing related to industrial technology using the modern advances of other sciences [1]. BIM technologies (BIM-design) are an effective tool for digitalizing design activities in shipbuilding.

It should be noted that conventional designing uses two-dimensional models of designed objects (plans, drawings, specifications), which is why the shipbuilding has not yet decided on the definitive understanding of an "information model" [2].

BIM technologies are based on a virtual 3D model that reflects real physical features [3]. However, it should be noted that these are not all resources of information modeling technology. Additional categories are added to it such as time, plans, cost. They make it possible to calculate and determine parameters for the project modeling processes even before it is implemented. Managing the model data helps shorten the project's implementation, simplifies the operation of the facility, and extends its lifespan.

Today, the introduction of modern technologies for the creation of new marine equipment is constrained by the lack of a single design theory for marine tethered systems (MTSs) with flexible links (FLs). That does not make it possible to take into consideration the full range of future performance of MTS with FL and extends the terms of the design work.

Advancing theoretical methods, technology, and design methodology using the principles of Shipbuilding 4.0 and BIM technologies could prove relevant for improving design activities in shipbuilding.

2. Literature review and problem statement

Work [4] reports the results of studying an integrated system consisting of two towed underwater vehicles and a free-floating probe. Two different approaches are considered for the dynamic analysis of the vehicle's towed system. The analysis is carried out using the MOSES simulation software. However, the FL performance is not considered. In addition, a given model does not make it possible to determine the relative position of the carrier vessel (CV) and submersible vehicle (SV) during their maneuvering as an important mode of operation. A way out of this situation could be the approach proposed in paper [5], in which the MM that describes the MTS dynamics makes it possible to determine the relative position of CV and SV during their maneuvering.

Work [6] examines the hydrodynamic model of a towed system. The model of the towed cable in the cited work is based on the Ablow and Schechter method. The main issue with UTS design is selecting the Euler angles and voltage at the endpoint of the cable. The work describes the model of a towed cable but a given model for describing UTS FL does not make it possible to investigate the maneuvering modes of the system, leading to the vibration of poorly streamlined FLs in the stream. The issues of a comprehensive approach to the design of towed systems are also not considered. The variant of overcoming the relevant difficulties may be the use of the developed mathematical model (MM) (7) in which the system of equations, describing the dynamics of the FL element as a result of the action of external forces and reactions of stretching, bending, and turning, is defined. The authors built an algorithm for modeling the FL dynamics, allowing them to perform the calculations of the dynamics of the MTS FL, and, in the future, to move to the development of software (SW) to describe the MTS dynamics.

Work [8] explores a method of motion control for a towed submersible vehicle (TSV) with movable wings. TSV is affected by the non-linearity and uncertainty of the position of the flexible towing cable, hydrodynamic forces, parametric fluctuations, and external disturbances. The cable is approximated by the method of concentrated masses, the number of cable segments determines the order of the system. Direct consideration of the non-linear dynamics is one of the main features of the cited work. However, the effect of hydrodynamic compression on the cable during its spatial movement is not considered. A way out of this situation could be an approach that implies creating a comprehensive model for the description of UTS dynamics.

Paper [9] examines a matrix method for analyzing the positioning system to determine the dynamic reaction of UTS. The equivalent linearization and the theory of small perturbations, as well as the model of pitching the towed body, are used. Two methods of application are considered. It is noted that the design of UTS is often limited by the dynamic stresses and deflections caused by the movements of a ship in stormy weather. The two main simplifications are common: small perturbations and equivalent linearization. In the first case, dynamic deflections are considered small movements from the static configuration, the shape of which is known. A given dynamic model is two-dimensional without taking into consideration the bending rigidity of FL, without intermediate elements of FL. A variant of overcoming the relevant difficulties may be the creation of an MM that describes the dynamics of MTS with FL, taking into consideration the effect of the FL bending rigidity on its deflection and the force of stretching. This is the approach used in [10].

Paper [11] attempts to address the task of describing the UTS movement as a three-dimensional dynamic computer model developed to study the two-tiered UTS by modeling cables and their dynamics. The cable system is modeled using a difference approach involving three degrees of freedom; six degrees of freedom of underwater towed bodies were used. However, a given model does not make it possible to determine the resonance modes of FL stretching and the maximum loads on FL in order to assess its strength in the process of maneuvering CV and SV. Issues related to large FL movements also remained unresolved. A way out of this situation could be the approach proposed in paper [5], in which the MM that describes the MTS dynamics makes it possible to determine the resonance modes of FL stretching and the maximum loads on FL in order to assess its strength in the process of maneuvering CV and SV. A comprehensive approach to the analysis of the towed system may be a variant to overcome such difficulties.

Work [12] reports a method of mathematical modeling of the FL dynamics based on the automatic control over the axial movement of its parts. The distance control between the FL elements as a component of MM was synthesized. A technique to model FL with a variable length is proposed. The effectiveness of the developed method in comparison with the method of concentrated masses and elastic bonds in the modeling of non-stretchable FL is shown, but a change in the hydrodynamic characteristics of FL under the influence of hydrostatic pressure is not taken into consideration. These mathematical methods of describing the FL dynamics were developed to improve automatic control, so issues related to the design of UTS were not considered.

Paper [13] examines a cable of variable length. The Lagrange method and the concentrated mass method are used in the analysis of the movement of the towed bodies (the calculations produce a greater error of FL approximation than when using the Hermit functions). The FL analysis uses a variable number of elements; the FL elasticity is taken into consideration. The FL model is three-dimensional but the results were obtained for a flat model. The reason for this may be objective difficulties associated with the complexity of describing the dynamics of MTS with FL. However, it should be noted that a given model does not give a pattern of changes in the rigidity of FL over time; in addition, the equations take a complex form and cannot be used in engineering calculations. This is the approach used in work [14].

Paper [15] examines the dynamics of the towing vehicle and the towed object. For systems where the weight of the towing vehicle is comparable to the mass of the towed vehicle, it is necessary to take into consideration their overall dynamics. A model has been developed that is designed to search for mines; the authors used the approximation of the concentrated mass for the towed vehicle in connection with non-linear numerical models of the controlled tow vessel. FL is modeled in differential approximation (with small perturbations in the form of FL) but the issues related to the description of the FL dynamics in large movements of FL in MTS remained unresolved. A way out of this situation could be the approach proposed in paper [10], which is to develop a MM of the FL element dynamics, which makes it possible to take into consideration the large movements of FL within MTS. Equations of the MTS FL element dynamics have been obtained, which make it possible to describe the significant values of its movements.

Until now, there is no unified design theory for MPS with FL (PPS and UTS), which would take into account all the essential factors of their operation and reliably allow them to be designed. The reason for the lengthening of the design time is usually the lack of scientific and technical groundwork, the unpreparedness of personnel to solve the problems that have arisen, the inconsistency of the design organization with the tasks to be solved, weak timing discipline of co-developers (co-executors) and counter-agents.

There are many tools to describe FL, mainly in a flat statement of the problem. Existing FL (MM) calculations are cumbersome and are used mainly for ideal round cross-sections and are not brought to the engineering application. The specificity of designing MTS with FL is that the design calculations must be carried out for the FL, which, from a mathematical point of view, are problems with unknown boundary conditions. This introduces certain difficulties and involves considerable time cost.

The unresolved problem in terms of the overall systemic approach is the difficulty of taking into consideration the operational characteristics of MTS with FL, loads that operating on FL, and the nature of this load.

However, the challenge of improving the design of MTS with FL is the need to make comprehensive use of existing methods to account for all information about MTS with FL. It is also necessary to develop the theoretical foundations of automated design of MTS with FL to reduce all types of expenditures, decrease costs, reduce design times, bring down the workload.

Our analysis of different classes of MTS with FL has revealed that the current structures have inflated mass-size indicators and material capacity. This affects the displacement and specifications of the UTS tugboat, leads to increased operating costs, reduces the competitiveness of these products in the market.

In connection with the increasing working depths of the use of MTS with FL, it is a relevant task to improve the theory and methods of designing MTS with FL, refining existing calculation procedures. This is because existing methods of calculation and design are either simplified and do not fully take into consideration the actual loads and the nature of loading MTS FL.

Thus, along with an in-depth presentation of particular issues of UTS modeling, the issues of the synthesis of reliable models of UTS operating regimes have not been sufficiently covered in the scientific literature. The issues of integrated application of the principles of Shipbuilding 4.0, BIM-design, and additive technologies have hardly been worked out so far in designing and constructing UTS.

The design methodology for MTS with FL is needed, based on MM that describes the dynamics of FL and MTS with FL, to explore the diverse operating regimes of different MTS classes. That would make it possible to devise recommendations for predicting possible loads for the design of their elements, improve existing methods of calculation and design of MTS with FL, and bring them to the level of engineering application.

All this suggests that a study on improving the design of MTS with FL is appropriate.

There is a task for designers to devise such a procedure for designing MTS, which would make it possible to receive competitive technical products. This is possible by reducing the time and quality of design, decreasing the material intensity of structures and energy consumption on board a carrier vessel (CV) of MTS, the "intellectualization" of the design processes and operation of the projected system. In addition, it is promising to use additive manufacturing technologies based on the results of 3D design, the use of Shipbuilding 4.0 principles, as well as BIM design.

3. The aim and objectives of the study

The aim of this study is to improve the process of designing MTS with FL taking into consideration their operational characteristics, based on a refined MM that describes the dynamics of FL and MTS with FL using the Shipbuilding 4.0 principles.

To accomplish the aim, the following tasks have been set:

– to devise the improved design concept (IDC) of MTS with FL using the Shipbuilding 4.0 principles;

– to build a special modeling complex (SMC) based on the software (SW) describing the dynamics of MTS FL and MTS with FL;

– to justify the application of the Shipbuilding 4.0 principles 4.0 and BIM technologies.

4. Materials and methods to study the process of designing maritime technical systems with flexible links

One class of maritime technical systems (MTS) is the class of maritime tethered systems (MTS), which, in turn, includes underwater tethered systems (UTSs) and underwater towed systems (UTSs). MTSs typically include several separate modules (links) and FLs connecting them, which provide the UTS with the necessary spatial configuration under a working mode. FLs used are steel and synthetic ropes, cargo cables, cables-ropes, chains, and other FLs capable of transmitting mechanical forces and provide for the necessary energy and information communication between UTS modules and its carrier. The UTS modules used could include the carriers of underwater equipment, underwater towed vehicles (UTV), diverting devices, etc.

Fig. 1 shows the composition of UTS equipment for two cases of towing: regular and reverse towing with ASW.

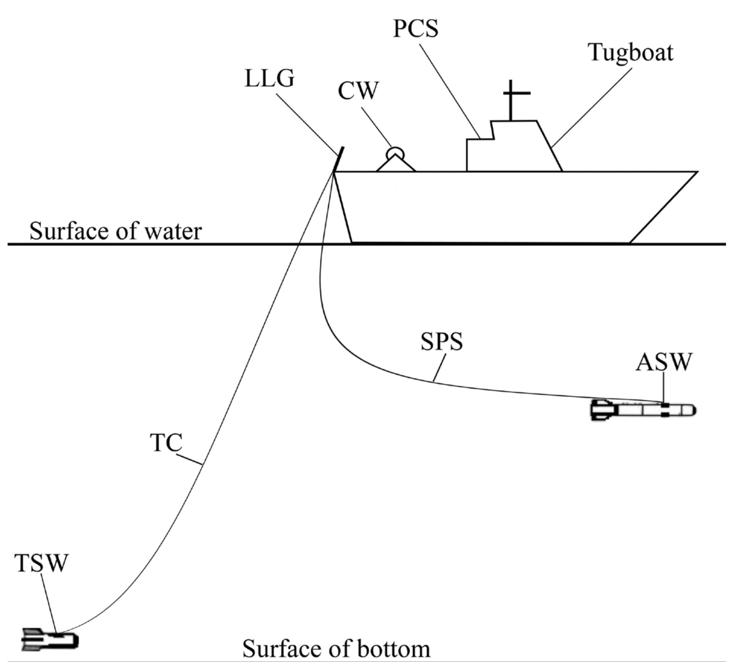

Fig. 1. UTS equipment structure

In the process of developing IDC and SMC, we have studied and analyzed available special literature, as well as the procedures and design standards in shipbuilding [16, 17].

The general scientific methods of research used include analysis, synthesis, structuring, generalization, analogy as the gnoseological basis of modeling, simulation.

Observation and model experiments have been applied as empirical methods. Particular theoretical models and laws were used as methods of theoretical research: formalization, axiomatic method, hypothesis, theories of different levels, etc.

5. The study results

5. 1. Developing an improved design concept (IDC) of MTS with FL using the Shipbuilding 4.0 principles

There are the following stages in design:

– creating a project concept (conceptual design phase);

– identify and solve the main objectives of the project at the model level (technical design phase);

– check the results and adjust the tools selected (testing phase);

– plan and implement the project (production planning and preparation phases; production and operation; disposal).

The improved design concept (IDC) of MTS FL as an integral part of the design process of MTS with FL implies building a comprehensive model for improving the design of MTS with FL (MM and SW). That makes it possible to take into consideration the internal and external factors of the environment that influence the operation of FL. It is also possible to take into consideration new properties of FL, previously not taken into consideration, which makes it possible to design MTS with FL and obtain reliable results in the early stages of research design. It also reduces all costs and improves MTS taking into consideration the specificity of MTS operation (internal and external environmental factors).

The concept's basic principles [18]:

– the principle of coherent goals: the main purpose of the concept is aligned with the aim of developing projects of the new MTS to ensure a better quality of optimal solutions already at the initial stage of design; it creates the basis for the successful implementation of the next stages – technical and working projects;

– the principle of a complete system: the level of detail for MTS captures in the concept those provisions that correspond to the level of detail of the element of an MTS system (for example, FL) for which it is being developed;

– the principle of basis uniformity (provides for the use of concepts for MTS with FL, which have unambiguous and the same interpretation, both at the level of the system element and the equal systems in general – this implies using the classifications of FL, MTS, UTS, and UTS);

– the principle of incomplete determinism and stochasticity provides for the absence in the concept of unambiguous precise values of indicators and parameters of elements of the system or MTS system in general;

– the principle of development: the concept's provisions should focus on the development of each element of the system (for example, MTS FL) and the system (MTS) in general;

– the principle of satisfaction for all participants stipulates that the provisions of the concept are devised so that none of the stakeholders (Customer, developers, and operators of MTS) and the person as the highest social value is worse off during their implementation and completion;

– the principle of the integrated approach implies the need to consider and predict the consequences of the implementation of the concept: the proposed improved design concept of MTS with FL would make it possible to develop a more advanced methodology for designing MTS with FL, taking into consideration the MTS modes of operation.

A short list of the most important tasks within the concept:

– taking into consideration the specific operating conditions of MTS FL and refine the issue related to external forces based on experience and model experiment, scientific research;

– analyze parameters of sea waves and various aspects of operation;

– study the technological processes of the use of FL (exploitation regimes) under marine conditions;

– assess possible emergencies and take steps to get out of them;

– select reasonable criteria for the strength of the elements of the system and their assessment;

– assess the reliability of FL and MTS elements;

– improve the design methodology to take into consideration the purpose of the object, the results from previous scientific research, existing advances in science and technology, and design experience.

This concept is based on the use of digitalization (using digital technologies) to process a large amount of digital information (so-called "big data"). That makes it possible, in the process of software-computational operations, in the automatic design of MTS with FL, to present data, in real time, electronically as a scientific and methodological basis for the process of automated design in the early stages of design (technical proposal and sketch design). This solves the task of improving the efficiency of design and saving time, as well as the total cost of the process to create a new article (object).

The use of a given IDC of MTS with FL would provide an opportunity to improve the competitiveness of a designed article (project), for example, by meeting the specific needs of the FL consumer in a better FL structure. In a given case, the competitiveness of the FL, obtained as a result of the use of the refined MM that describes the dynamics of FL and MTS with the FL, manifests itself in the system of creating technical and economic parameters of FL at all stages of its design, manufacture, pre-sales and after-sales maintenance, and consumption (operation).

Implementation of a given concept would also make a definite contribution to the development of projects of new ships and vessels carrying MTS with FL as it would provide a higher quality of optimal solutions already at the initial stage of design. It would provide the basis for the successful implementation of the following stages of technical and working projects.

According to the unified design documentation system (UDDS), designing a new article consists of the following stages [16, 17]:

– compile a technical task;

– calculate a technical proposal;

– develop a sketch project;

– prepare working design documentation (WDD), execute rule control, patent and metrological examination;

– manufacture and test a prototype;

– adjust working project and issue a preparatory batch of the article;

– check, coordinate, make changes, approve, and transfer documentation to the chief technologist's department.

The technical task (TT) for the design of MTS with FL is usually drawn up together with representatives of the Customer and the Manufacturer. It reflects the tactical and technical requirements of the Customer, indicating the conditions and modes of operation of the MTS. It also states the necessary technical parameters and characteristics, the resource or lifespan, planned output, safety and hygiene regulations, patent purity, terms and conditions of storage, design, transportability, additional or special requirements.

The technical proposal (TP) for the design of MTS with FL contains calculations of technical parameters and economic efficiency, which justify the possibility and feasibility of the development of the new article. Here, one must select, from the available database (DB):

– a tugboat project from the existing database (tugboat BD);

– a list of necessary equipment and volumes of PCS from the existing DB (PCS DB)

– a type of cable winch (CW) from the available database (CW DB);

– a type of LLG from the available database (LLG BD);

– a type of TC from the available DB (TC DB);

– a type of TSV from the available DB (TSV DB).

The calculations are carried out in several variants, analyzed, and the best variant is selected, which has the greatest expected economic effect. Once agreed or approved, TP is the basis for the next stages of design preparation of the project.

The sketch project (SP) of the designed MTS with FL is developed in several variants; if necessary, a model of the article (mock-up) is made, after which the adopted version is approved. SP should give an overview of the device and the operational principles of the new article. After final approval, SP is the basis for the development of a technical project.

The technical project (TPro) of the projected MTS with FL is developed on a certain scale, in accordance with the requirements of standards (different types, projections, sections with appropriate dimensions to represent the device and operation of the new article). TPro refines the drawing of the general type of article, the drawings of the main units and nodes, their specifications, installation and assembly schemes with calculations for durability, as well as other parameters, are prepared. It substantiates the choice of materials for the most responsible parts, compiles instructions for the consumer's use of the article, an explanatory note is written. The TPro is coordinated with the Customer, after which they decide to perform a working project.

Working design documentation (WDD) – a working project (WP) is worked out after the approval of TPro. It represents working drawings of all parts (except normals), which indicate the necessary sizes, projections, views, incisions, sections, material, etc. These drawings are used to fabricate MTS parts at a manufacturing plant.

The established design scheme of MTS with FL is shown in Fig. 2.

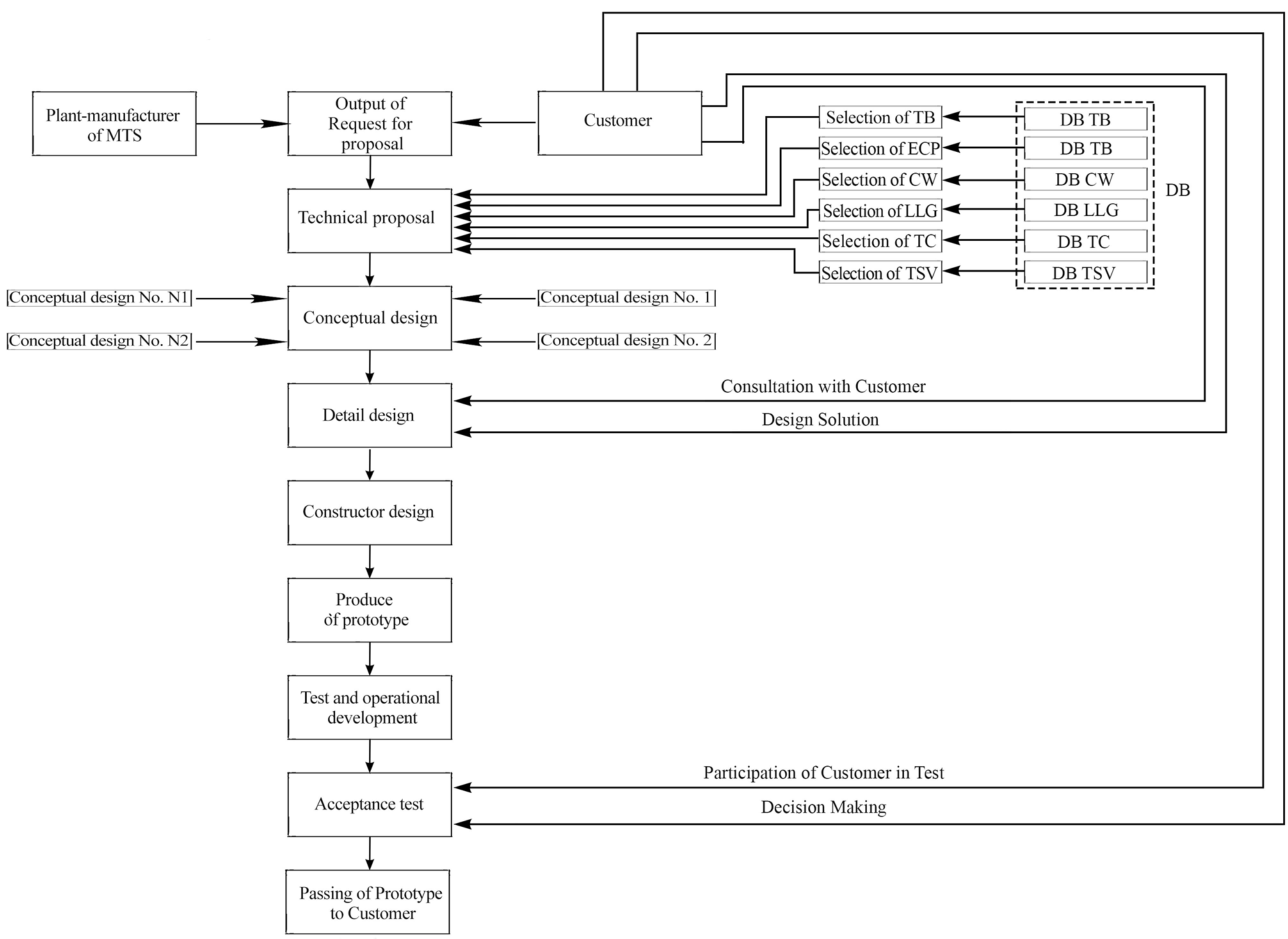

Fig. 2. Scheme of designing MTS with FL using a conventional technique

The algorithm consists of the following basic stages:

1. Customer's issuance of technical requirements for the design of MTS in the Design Bureau (DB).
2. Issue a Technical proposal for the design of MTS by the Customer in DB.
3. Customer's issuance of a Technical proposal to DB for the design of MTS with FL.
4. Sketch design of the projected MTS with FL.
5. Technical project of the projected MTS with FL.
6. Working project.
7. Make a prototype.
8. Test and refine the MTS.
9. Purchasing tests of the new MTS.
10. Transfer the prototype to the Customer.

The results of the design and development work (DDW) at each stage are coordinated with the Customer. The DDW begins with the development of the concept of solving the task by means of shipbuilding and other industries and the formulation of the basic requirements for MTS. Restrictive conditions (by cost, dimensions of Tugboat, crew size, building conditions, etc.) are defined.

Based on the development of possible solutions, together with the Customer, they choose the best variant. Of the possible equivalent variants of the design solution, they, as a rule, choose the variant most beneficial for the manufacturer of MTS.

5. 2. Creating a special modeling complex to design MTS with FL based on SW that describes the dynamics of MTS FL and MTS with FL

The proposed SMC, which is based on the MM and SW that describe the dynamics of MTS FL (and MTS with FL) [19], makes it possible to improve the existing methods of calculation and design of MTS with FL and bring them to the level of engineering application. It also makes it possible to investigate different modes of MTS operation, to obtain the values of forces operating on the FL (and in it) and working bodies of CW, to assess the real destructive efforts in the FL and MTS, to develop recommendations for predicting possible loads, to reduce the mass-size characteristics of ship deck devices [20].

SMC makes it possible to conduct a model experiment without referring to a physical experiment. At the same time, it is possible to simulate the various modes of operation of the projected MTS with FL, up to extreme and emergency. These regimes are very difficult to create under natural conditions, and sometimes it could be just dangerous for the MTS tugboat, crew, and personnel, and could lead to material losses at best.

Thus, the SMC is a kind of simulator for the designer. Different variants could be recorded and stored to create and accumulate databases for different MTSs. At the same time, the information is obtained not from a physical experiment but from a model idea of physical reality. This approach is used when actual experiments are difficult due to financial or physical limitations or could lead to unpredictably dangerous results.

The use of the developed SMC would save material resources (inflated dimensions of SMP or FL lead to increased fuel consumption for Main Power-Plant (MPP) CV, an increase in the power of CV MPP, electrical equipment, as well as increasing their dimensions). This also leads to an increase in the volume of ship premises and the dimensions of Tugboat. This approach would also provide detailed data on real loads in FL. That, in turn, would minimize the strength ratios used in calculating the SPM parts for durability, or completely abandon their use in MTS design calculations [20].

CW simulation of the dynamics of FL and MTS with FL is developed in the Delphi system based on an algorithm for solving the system of equations in the MM of the MTS dynamics [19]. A working window of the software on a computer screen contains windows for setting the parameters' values (from 37 to 67) for MPS and 4 parameters of the algorithm. To the right of these windows, the names of the parameters and their dimensionality are briefly described.

When running the program, the user could observe on the diagrams in its working window a change in the position of the nodes of FL elements, at the ends of which large markers show the coordinates of CV and SV, as well as a change in the forces of stretching the FL at the nodes of its elements. That makes it possible to quickly determine the correctness of the parameters of the MTS under the specified modes of movement of CV and SV under the conditions of sea currents, sea surface disturbance (blue line on the charts) and interaction of elements of the MTS with the seabed.

Simulation results appear graphically on seven diagrams at the specified time points that are shown in the window next to the diagrams. These moments are determined by the time interval through which the images change on the diagrams and are set by the "visualization step, s" parameter. Three diagrams show the spatial location of SS, FL, and SV in projections onto the $X0Z$, $Y0Z$ and $X0Y$ plane of the rectangular Cartesian coordinate system, while the fourth diagram shows the distribution of the force of FL stretching along its length (coordinate S). In the first three diagrams, the range of coordinates is continuously changing, adapting to the location of MTS at the current point in time. The sixth diagram shows data on the change in the time of the forces of tension of FL operating on SV and CV. If the SV circulation mode is enabled (the speed of its circulation is not zero), then the diagram shows a change in the power of the SV engine.

Fig. 3 shows the working window of the UTS dynamics modeling program after the initial data are entered. The working window of the program contains windows for setting 38 MTS parameters and 3 algorithm parameters. To the right of these windows, we briefly recorded the name of the parameters and their dimensionality.

Fig. 4 shows the working window of the UTS dynamics modeling program after its completion when the FL is on the float, and it overcomes the obstacle.

SW was tested as a test [21]. The mathematical model of a tethered system and the calculation algorithm were tested using the examples of a stationary towing mode for three types of tethered systems.

The SW design makes it possible to expand the existing CW that simulates the dynamics of MTS FL with the emergence of new (additional) tasks (regimes that could be calculated with the help of a given SW):

1) to describe the mode of FL towing (47–53 parameters are taken into consideration by SW);

2) to describe the collision of FL with obstacles (56 parameters are taken into consideration by SW);

3) to describe the impact on FL from a counter underwater object (66 parameters are taken into consideration by SW);

4) to describe the circulation regime of CV with UTV (61 parameters are taken into consideration by SW);

5) to describe the BNP regime at anchor (61 parameters are taken into consideration by CW);

6) to describe the mode of accounting for the bending stiffness and stretching of FL (67 parameters are taken into consideration by SW);

7) to describe the mode of accounting for the torsion regime of FL (67 parameters are taken into consideration by SW);

8) to describe the mode of vibration of FL 61 parameters are taken into consideration by SW).

We shall take a closer look at the stages of the design process of MTS with FL based on the use of SPS and SMC (Fig. 5, 6).

1. Issuance of Technical requirements (TR) by the DB Customer for the design of MTS. The design process begins with figuring out the purpose of the MTS (answering questions: what the system is created for, where, when, and at what time it would be used). MTS requirements (reliability, payload capacity, duration of autonomous action, etc.) are formulated.

Then the restrictions imposed by the features of the marine environment (the state of the sea, wind force, hydrostatic pressure, exposure to marine organisms, corrosive destruction, etc.) are formulated. The choice of the type of MPS (surface, deep, single-anchor, multi-anchor, etc.) is made. The design type of the system is specified and mechanical loads are evaluated.

DB analyzes TR in conjunction with the manufacturer and transfers its results to the Customer. The DB is already addressing the MTS IDC at this stage.

2. Preliminary design (research design stage). This stage makes it possible, at the research design stage, to use the improved design concept of MTS with FL, before the issuance of TR, to carry out search studies. This approach would reduce a series of stages of the design process and enable the identification of MTS form and its elements at an early stage of design. It is carried out with the participation of DB. The results of the search (research design) are passed on to the Customer.

3. The issuance of TR for the design of MTS by the Customer of the DB. It is made together with representatives of the Customer and the Manufacturer. At this stage, the Customer's tactical and technical requirements (TTR) are displayed, which must contain the conditions and modes of operation of the MTS. They also include the necessary technical parameters and characteristics, resource or lifespan, planned output, features of the external market where the MTS is to be sold, the terms and conditions of storage, transportability capabilities, additional or special requirements. The DB analyzes TR in conjunction with the manufacturer and transfers its results to the Customer.

4. The customer's issuance of TPR PKB for the design of MTS with FL. It contains calculations of technical parameters and economic efficiency, which justify the possibility and feasibility of the development of the new system. It selects MTS components from available databases:

– tugboat project from the existing database (CV DB);

– a list of necessary equipment and volumes of PCS from the existing DB (PCS DB);

– the type of CW from the available database (CW DB);

– the type of LLG from the available database (LLG DB);

– the type of TC from the available database (TC DB);

– the type of TSV from the available database (TSV DB).

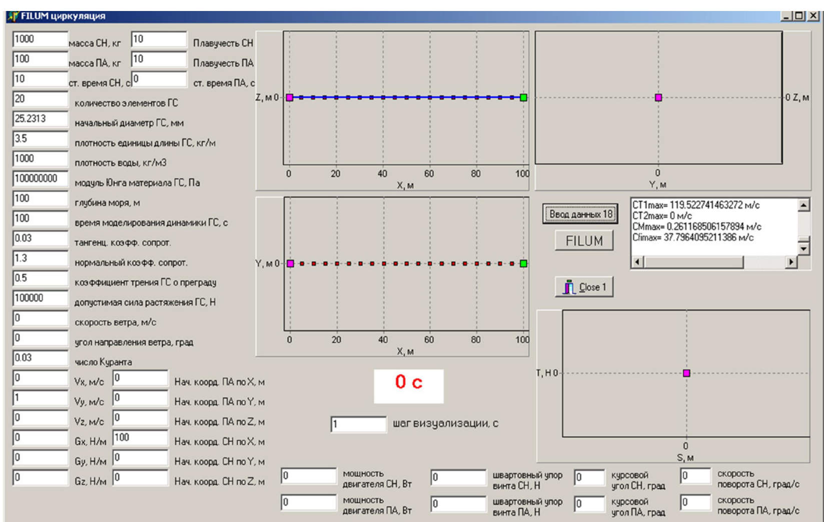

Fig. 3. Working window of the UTS dynamics modeling program after the original data are entered

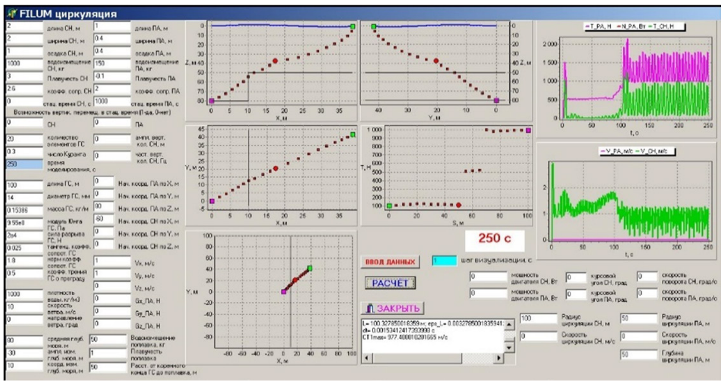

Fig. 4. Working window of the UTS dynamics modeling program after its completion

The calculations are carried out for several variants using the MM and SW that describe the dynamics of MTS FL and MTS with FL, they analyze and select the best variant, which has the greatest expected economic effect.

Possible design process variants:

1) there is a certain project of a tugboat. Given this, the choice of PCS, CW, LLG, and TSV is made in relation to the existing type of vessel. These procedures are limited by the displacement of the tugboat and are carried out depending on the tactical and technical characteristics (TTC) of a given tugboat;

2) the design is based on the customer's requirements for TSV. On this basis, the choice of the tugboat, PCS, CW, TC, and LLG is made on the basis of the requirements for TSV. This implies the ability to transfer the necessary amount of energy to the TSV, transmit and obtain the necessary amount of information, ensure the necessary mobility and agility of the TSV at the specified depth, etc.;

3) designing a new MTS with FL that did not exist before. The design begins with determining the requirements for TSV and TC (the required length of TC). On this basis, the requirements for the capacity of the CW drum are defined.

Once the MTS components have been agreed or approved, the Technical proposal is the basis for the subsequent stages of design preparation for the project.

At this stage (phase 4), the SMC is used to assess the most appropriate MTS variant. Assessment of the operation of the new MTS is carried out with the help of the SMC (software that describes the dynamics of MTS with FL, taking into consideration the developed MM for the description of the dynamics of MTS FL).

The 3D model of MTS with FL (the MM to describe the dynamics of FL and MTS with FL) is associated with databases of both MTS and its components (tugboat, PCS, CW, LLG, TC, TSV). The peculiarity of the use of a given MM in design is that the MTS with FL is actually designed as a whole: changing any component parameter entails an automatic change of the associated parameters and objects to drawings, specifications, visualizations, design schedule, etc. inclusive.

Next, the DB analyzes TR together with the MTS manufacturer and transfers its results to the Customer.

5. Sketch project of the designed MTS with FL. The SP provides an overview of the structure and operational principles of the new MTS. It is developed in several variants. This is similar to stage 4, and the MTS's sketch projects are selected from the available databases. After the choice of SP, the adopted variant is approved, which is the basis for the development of the TPro. Budgetary constraints and logistical constraints are also taken into consideration.

If one gets an idea of MTS with FL at the TPro stage, it is possible to abandon the sketch design phase.

The IDC for MPS with FL and the developed SMC are used by the Designer (DB) on stages 1–5 of the MTS with FL design improvement algorithm.

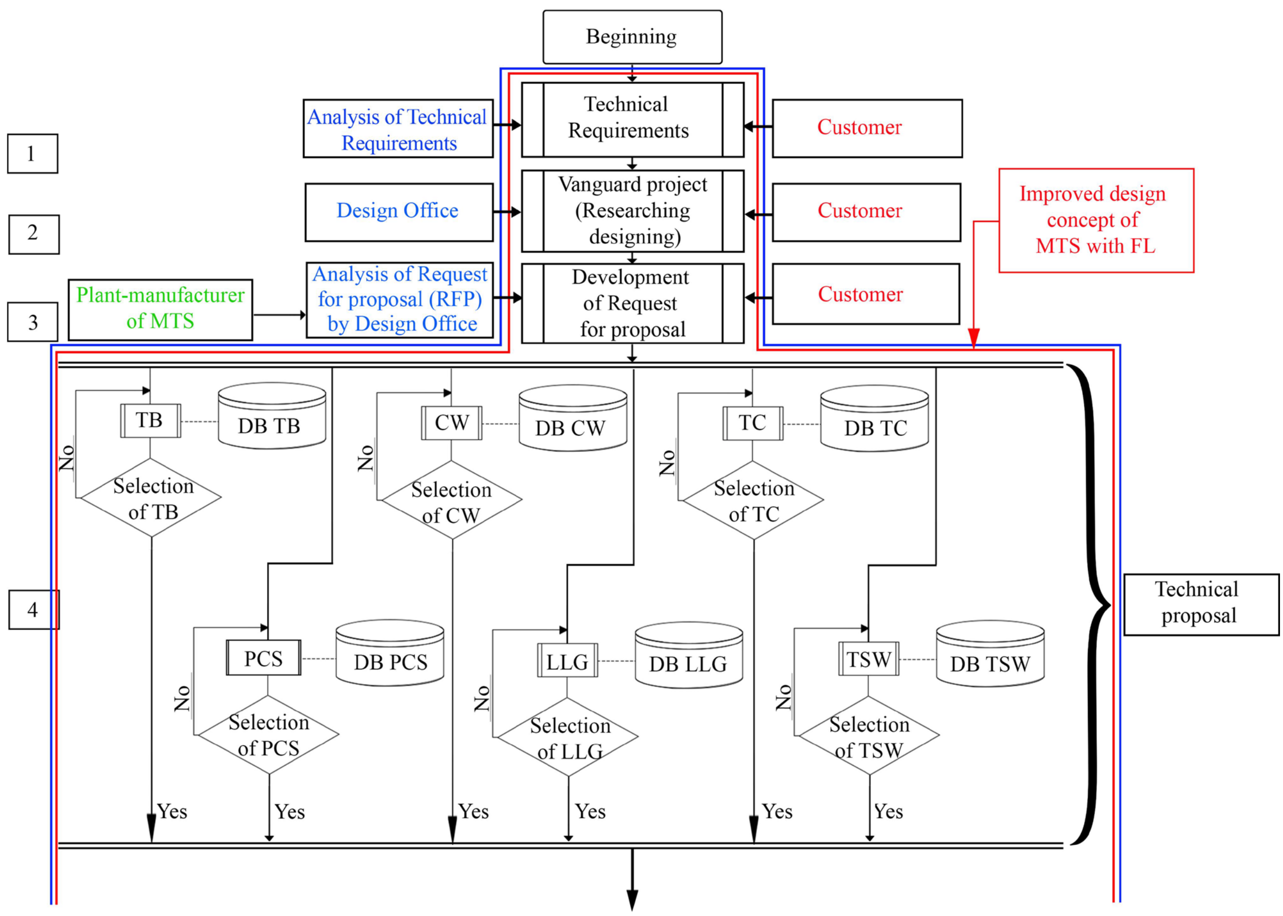

Fig. 5. Scheme of design algorithm of MTS with FL

6. Technical project of the designed MTS with FL. It is developed on a certain scale, with compliance with the requirements of standards. The TPro clarifies the drawing of the general type of the system, the drawings of the main units and nodes, their specifications, installation and assembly schemes with calculations for durability, as well as other parameters. The TPro is coordinated with the Customer, after which they decide to perform a working project.

7. A working project. The WP is developed on the basis of TPro after its approval. It also develops WDD, which includes working drawings of all parts and nodes, which indicate the necessary sizes, projections and views, incisions, sections, material, etc. CAD systems are applied using BIM technologies. Then they manufacture the parts of the MTS at the Manufacturing Company. The entire MTS for patent purity is also tested here, similar to the accepted design practice. When assembling and testing, it is possible to refine the design of individual parts and adjust the WP.

8. Manufacturing of an MTS prototype. It is carried out by the Manufacturer. At the same time, the DB supervises and advises the manufacturer, if necessary, promptly makes the necessary changes in the WDD. Customer participation in this process is possible.

9. Testing and refining the MTS. It is carried out by the Manufacturer. At the same time, the DB takes part in the testing of the system. The Customer could also take part.

10. MTS acceptance tests. The MTS manufacturer conducts the acceptance tests, and the Customer carries out the test. The DB is sure to take part. According to the results of the acceptance tests, the Customer, the Manufacturer and DP sign the Acceptance act. A decision is then made to produce the newly designed MTS.

11. Transfer of a prototype to the Customer. The MTS prototype is given to the Manufacturer for further testing and pilot operation.

There is no such approach in the accepted engineering design (CAD), so it is necessary to use the proposed integrated MM to improve the design of MTS with FL as the components of Shipbuilding 4.0 and BIM. The use of 3D MTS models is associated with the MTS database as well as its components instead of two-dimensional models of design objects, which makes it possible to design MTS as a whole. In this case, changing a parameter of the component of the system (for example, FL) results in an automatic change of the associated parameters and objects to drawings, visualizations, design schedule, etc. inclusive. Thus, the creation of IM should cover the entire period from the creation of the idea of the project to the completion of the MTS operation and disposal.

Improving existing methods of calculating and designing MTS with FL based on the developed MM makes it possible to bring them to the level of engineering application. In a given case, a given method of improving the design of MTS FL and MTS with FL is new, unparalleled in the market of a given product.

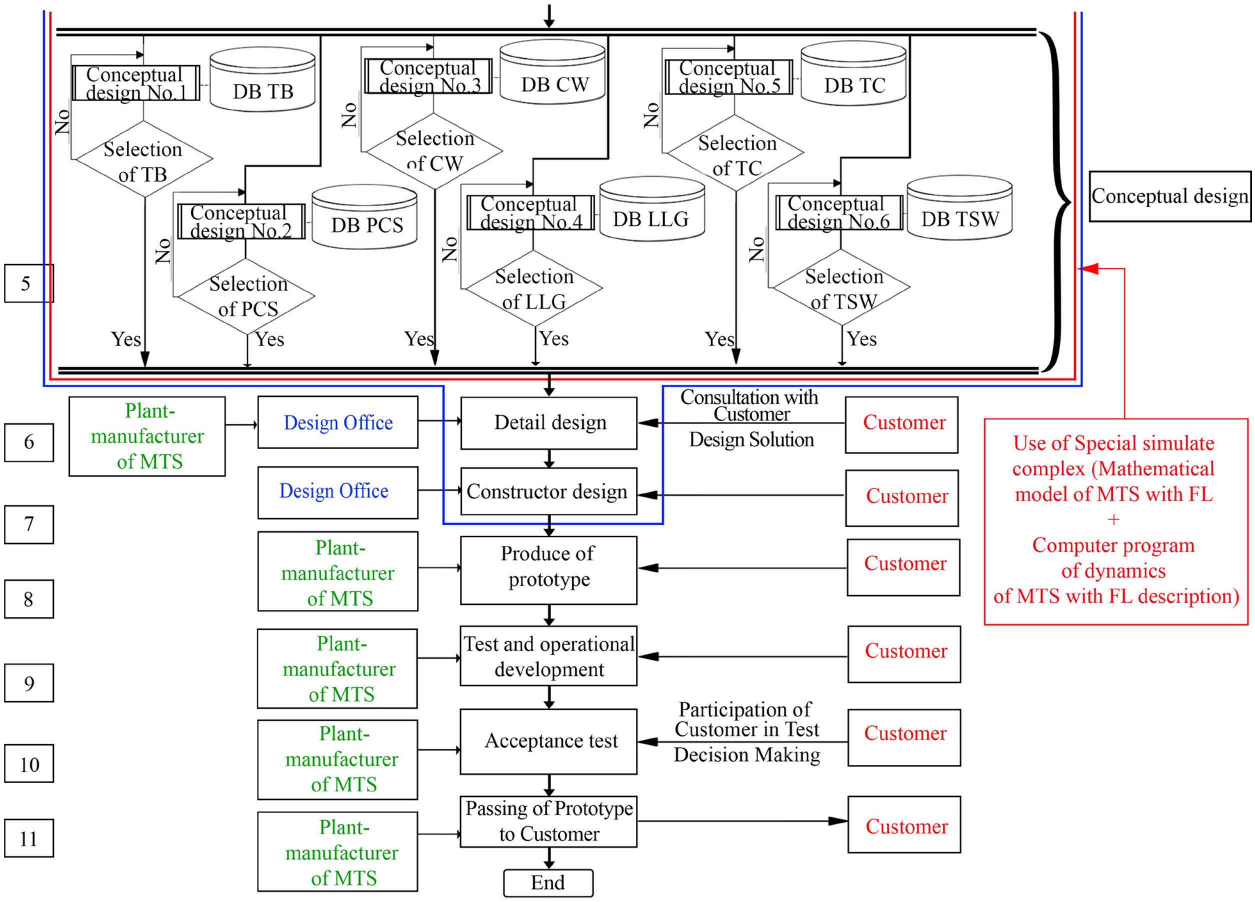

Fig. 6. Continuation of the scheme of design algorithm of MTS with FL

5. 3. Applying the principles of Shipbuilding 4.0 and BIM technology in the design of MTS with FL

Consider applying BIM (IM or modeling) using an example of the improvement of UTS design. It is proposed to use the principles of Shipbuilding 4.0 [22] and BIM, which would make it possible to obtain reliable engineering solutions already in the early stages of design (in the development of a preliminary design, technical task, and technical proposal).

BIM design tools [3] make it possible to acquire different kinds of information materials from the model of an object for creating drawings and for other purposes. The BIM software also defines objects as the parameters of relationships among other objects. Therefore, when changes are made to a related object, dependent objects also automatically change. Each element of the model could include attributes for their automatic selection and ordering, providing an opportunity to estimate costs as well as account for resource usage.

Information modeling processes and technologies have evolved over the past decades and originate long before BIM modeling. Its emergence is associated with the IM of buildings and structures. BIM (building information modeling) is based on a virtual 3D model that has real physical properties. Sometimes BIM is called smart modeling.

BIM technology (Business Information Modeling) refers to new technology and a new way of working [23]. Attempts to apply BIM in various fields of activity are observed. The use of models facilitates the design process at all stages while ensuring careful analysis, regulation, and control, that is, using general management functions. This avoids many setbacks, such as in construction (reducing waste, creating value, and increasing productivity), that is, BIM is a business process that is supported by technology. Through cooperation in this area, all participants in the process (project creation) have access to the same information about the project, cost, and planning throughout the project implementation and in real time. Modeling the information component is the process of creating and managing data throughout the creation and implementation of a project.

BIM design differs significantly from other types of design work. Its differences are the collection and processing of data on architectural, design, economic, technological, and operational characteristics of the object, united in a single information field (BIM-model). At the same time, all the data embedded in the object's information model (IM) are related and interdependent.

Improving the design of MTS with FL using the principles of Shipbuilding 4.0 and BIM technologies is illustrated in Fig. 7.

The expected potential of BIM is a relatively new technology in the field of shipbuilding, which is slowly adapting to change. BIM could assist with the design process (especially in the early stages) because it addresses key issues such as cost management and project management in general.

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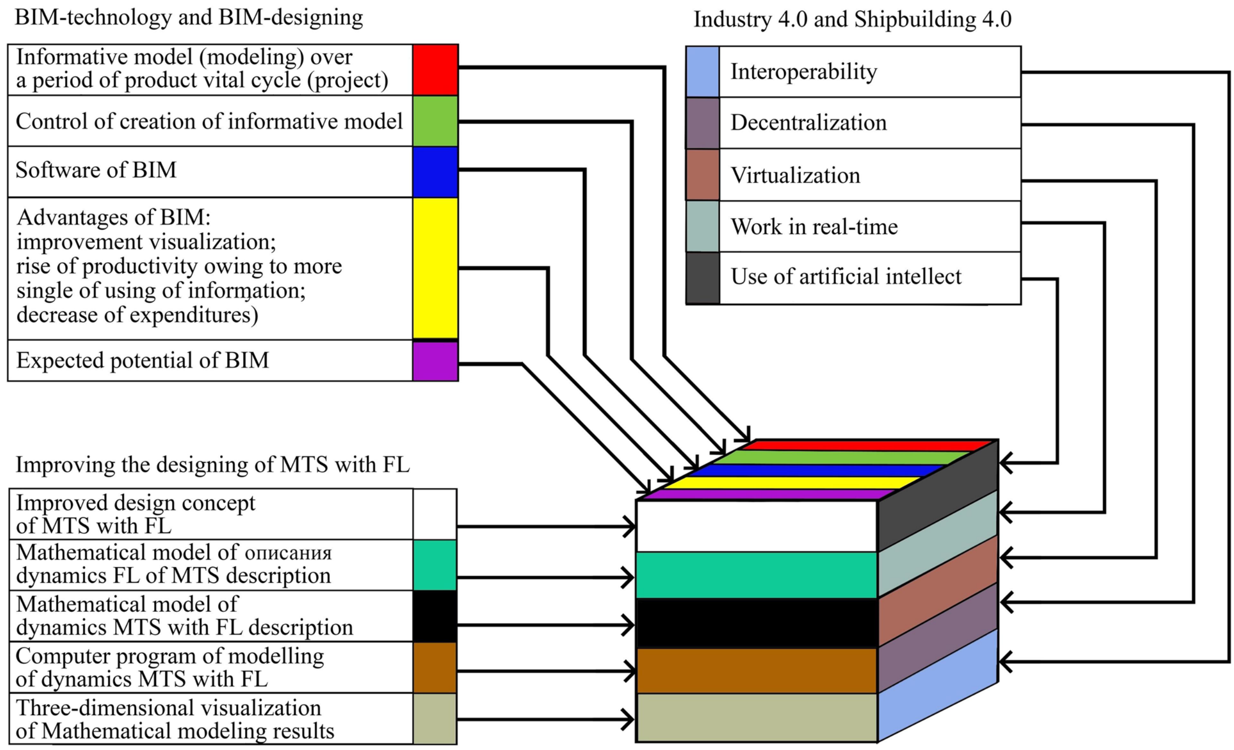

Fig. 7. The relationship between Shipbuilding 4.0 and BIM design and the process of improving the design of MTS with FL

Benefits of using BIM technologies include:
– immediate access to any project information;
– high-quality control of the design process at all stages;
– avoiding collisions and inconsistencies in projects;
– a significant reduction in the cost of designing and building MTS;
– the rational use of material and temporal resources.

It should be noted that if Shipbuilding 4.0 is an ideology, a kind of policy, then BIM is a common resource of knowledge for obtaining information about the object. This is a solid basis for making decisions throughout its life cycle, from concept creation to recycling. BIM could be considered part of the control function, which is part of the ideology of Shipbuilding 4.0. Thus, Shipbuilding 4.0 as an organizational and methodological basis (technology) is at the heart of new thinking.

6. Discussion of results of studying the design process of marine MTS with FL

It should be noted that current design methods in shipbuilding do not satisfy designers, which also requires a change in the existing design concept. The new IDC proposes to take into consideration the additional structural and operational characteristics of FL, which makes it possible to:
– assess the forces of the FL more accurately;
– take into consideration the new properties of FL (bending and torsion), which allows more accurate determination of FL configuration, especially, its running end;
– embed bending rigidity in the design of FL and MTS.

The main features of IDC for MTS with FL are:
– the application of classical methods of design theory, taking into consideration the features (specificity) of MTS design, depending on the type of MTS;
– the synthesis of classical methods and research design using the created MM, refining the results of optimization of the elements and characteristics of the object, obtained on the basis of the developed mathematical and computer models of MTS;
– the development of MM of the dynamics of MTS FL and MTS with FL and their reflection of characteristic physical processes during the creation of a specific MTS with FL;
– the development of a computer program to describe the dynamics of MTS FL and MTS with FL;
– optimizing the elements and characteristics of an object as a system at all levels of its hierarchy and at all stages of design as reliable information accumulates (an example of this hierarchical level is equipping the object with the basic elements of the system (equipment);
– organizing the interaction among a designer, the customer, the developers of the head equipment, as well as feedback of the stage-specific results to the initial technical tasks for MTS with FL and related equipment;
– improving the robustness of optimal solutions by examining the technical capabilities of MTS with FL in emergency and ensuring the overall safety of MTS with FL.

The comprehensive refined MM that describes the dynamics of FL has made it possible to use a mathematical apparatus, the application of which in practice allows the designer in the early stages of design to obtain reliable estimates of the structural and operational properties of FL [5, 10], which could significantly reduce the time and cost of design work.

The developed SW that describes the dynamics of MTS with FL [22] is a tool to model different operating modes and could prove extremely useful for the MTS designer and engineer. Its use practically makes it possible to refuse to conduct expensive field experiments. The proposed model makes it possible under comfortable laboratory conditions to simulate many operational modes of UTS and underwater towed systems in real time (up to extreme and emergency), which are very difficult to create under natural conditions. In a given case, when considering the various operational variants (regimes) of MTS with FL, the destruction of FL or an MTS element would occur conditionally. Different variants could be recorded and stored. In this way, a database for different MTS-specific regimes is created and accumulated.

The variety of operational tasks has led to the complexity and further improvement of the developed SW that describes the dynamics of MTS FL. In the study of the towing process, 38 parameters were initially taken into consideration by SW, then 58 parameters were taken into consideration [19]; 67 parameters were taken into consideration by SW when studying the emergency modes of MTS operation when the FL collided with a marine object (Fig. 3, 4). Testing SW has shown its good agreement with previous studies [21].

The derived MM to describe the dynamics of MTS FL and MTS with FL [7] have allowed the development of SMC, which makes it possible, in the design process:

– to take into consideration the specific operating conditions of MTS FL and refine the issue of external forces based on experience and model experiment, scientific research;

– to analyze the parameters of sea waves and various aspects of operation;

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– to explore the technological processes of FL use under marine conditions;

– to assess possible emergencies and take steps to get out of them;

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– to explore the technological processes of FL use under marine conditions;

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– to reasonably select the criteria for the strength of the elements of the system and evaluate them.

An attempt has been made to approach using information models (IM) in the process of improving the design of MTS with FL using an example of UTS through the application of a special modeling complex (SMC). Its employment implies the collection and comprehensive processing of all necessary data (design, technological, other information with all its relationships and interdependences). At the same time, MTS in the design process is considered as a single object with all its elements that are related to it.

With the help of SMC, the cost of design work would be reduced because of a smaller number of designers (instead of a team of designers of 4–5 people, they would need 1–2 people) and speed up the design time (the timeframe could be reduced by 3–4 times). Already in the early stages of the design, this would give an opportunity to obtain a concrete practical result because already at this stage it would be possible to get ready-made design results as well as reduce the scientific labor intensity of work performed, as there are already developed MM and SW for the descriptions of the dynamics of MTS with FL used in the design.

The proposed method of improving the design of MTS with FL, based on the MM of the dynamics of MTS FL and MTS with FL, makes it possible to investigate different modes of operation of almost all MTS classes, as opposed to existing methods. This allows it to be used as a procedure of engineering calculations to develop recommendations for predicting possible operational loads for the design of MTS elements with the necessary properties and parameters. A given method of designing MTS also makes it possible to abandon the physical modeling of MTS with FL associated with the field tests on high seas.

The reported results in the form of IDC and SMC make it possible to improve the design of MTS with FL taking into consideration the purpose of an object, the results of previous scientific research, existing advances in science and technology, as well as design experience.

Using a comprehensive system to improve the design of MTS with FL makes it possible to reduce the number of design stages of MTS at the stage of research (pre-research) design as the use of SMC eliminates the need to employ the next stages of design (No. 6, 7).

The advantage of this study, compared to ones in this area [4, 6, 9, 11, 12], is a new approach to design using the developed IDC and SMC, which make it possible to better design MTS with FL. The visualization and digitalization features provide the benefits of the proposed design improvement method.

An alternative solution, one could propose devising a guideline for shipbuilding that would take into consideration the principles of Shipbuilding 4.0 and BIM technologies.

The issue with the proposed method of improving the design of MTS with FL may be that BIM technologies are just beginning to be mastered; in shipbuilding, there is still no proper understanding of what the information model is [24–26]. Because BIM design differs significantly from existing design activities, special BIM managers (virtual designer VD or VDCPM project manager) are required to ensure effective information process management throughout the design and product development period, which may be a limitation on the use of BIM technologies. A BIM manager is hired by the development team on behalf of the client (for example, Customer) starting with the pre-design phase (TR received by the developer from the Customer). He/she oversees the development and monitoring of the progress of object-oriented BIM design in accordance with the projected indicators. He/she also provides support for the object's interdisciplinary IM components that manage analysis, charts, dynamics, and logistics.

The limitation of this study is the complexity of the mathematical apparatus used to develop an MM for the description of the dynamics of MTS with FL [5, 7, 10]. This study should be advanced towards further improvement of MM, SW, and SMC.

7. Conclusions

1. The improved design concept for MTS FL and MTS with FL is to improve the design of MTS, making it possible to take into consideration the internal and external factors of the environment affecting the operation of FL, and to create advanced MTSs. At the same time, it is possible to take into consideration the new properties of FL that were not previously taken into account. Previously, FLs were calculated on the basis of a breaking force, which led to an increase in the size, material capacity, and weight of FL and ship cable winches. The use of IDC for FL and MTS with FL would improve the competitiveness of the designed article (FL and MTS in general), reduce the cost, and decrease the design time of MTS with FL because already in the early stages of design it makes it possible to obtain a practical result and reduce the scientific workload of related activities.

2. The created SMC is based on MM and SW for the description of the dynamics of MTS FL. The originality of a given MM for the dynamics of MTS FL and MTS with FL is that it makes it possible, in real-time, in the dynamics, under different parameters of FL and MTS, to determine the limits (opportunities) of the studied (assigned) FL for these CVs and SVs. A given SMC makes it possible to obtain reliable engineering solutions in the early stages of design (in the development of a preliminary design, TR, and TPro).

3. The originality of the proposed method of improving the design of MTS with FL is to apply the ideology of digitalization in the context of following the global concept of using the principles of Shipbuilding 4.0 and BIM. In the field of science, new technologies are aimed at accelerating calculations and computations. In addition, a uniform system would allow scientists in different parts of the world to exchange data automatically in the shortest time.

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INTELLECTUAL PROPERTY ASSESSMENT: DEVELOPMENT OF INFORMATION AND METHODOLOGICAL SUPPORT IN CONDITIONS OF LIMITED INFORMATION

T. Momot
Doctor of Economic Sciences, Professor, Head of Department*
E-mail: tvmomot@gmail.com, momot@kname.edu.ua
M. Karpushenko
PhD, Associate Professor*
E-mail: Mariamaria1864@gmail.com
S. Prilipko
Doctor of Law, Professor, Head of Department
Department of Private Law
Law and Management Institute of the
Yaroslav Mudryi National Law University
Metalistiv str., 17, Kyiv, Ukraine, 03057
E-mail: sn.prylypko@gmail.com
N. Mushchynska
PhD, Associate Professor
Department of Land Administration and
Geographic Information Systems**
E-mail: muschinska@gmail.com
D. Momot
Postgraduate Student*
E-mail: momotdaryna@gmail.com
*Department of Financial and Economic Security,
Accounting and Auditing**
**O. M. Beketov National University of Urban Economy in Kharkiv
Marshala Bazhanova str., 17, Kharkiv, Ukraine, 61002

Assessment of intellectual property is an important process of commercialization of scientific and technical developments of enterprises of all forms of ownership. This is carried out to determine the value of intellectual property objects (IPO) in connection with the transfer of ownership (purchase, sale) to the corresponding object, the conclusion of a license agreement for the IPO use, accounting for IPO in accounting, contributed to the authorized capital, etc. Under such conditions, the problem of IPO underestimating significantly reduces the efficiency and effectiveness of enterprises. At the same time, the uniqueness of many types of intellectual assets and the impossibility of their visual assessment determine the expediency of systematizing methodological approaches to assessing the value of intellectual property assets to ensure an objective assessment of the value of intellectual property. This will help increase the profitability and business value of the enterprise.

The aim of research is to develop theoretical and methodological provisions and substantiate practical recommendations for improving information and methodological support for assessing the value of intangible assets, taking into account the requirements of regulatory documents and the availability of the necessary information. Based on the results of the study, methodological approaches to determining the value of intangible assets are systematized. According to the financial statements, the value of intangible assets of the leading enterprises of Ukraine and their share in the total value of assets were analyzed. The features of the assessment of intangible assets in accordance with accounting standards have been determined, a methodological approach to the assessment of the value of intellectual property has been developed, it allows to reasonably choose a method for assessing IPO based on the analysis of available information. It is proved that the lack of objective information on the value of IPO significantly reduces the value of assets of Ukrainian enterprises in comparison with the leading companies in the world, reduces their investment attractiveness and does not contribute to economic development

Keywords: intellectual property, intangible assets, income approach, comparative approach, cost approach

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1. Introduction

In modern conditions of the digital economy, the number of commercial transactions carried out with objects of intellectual value is constantly growing. Such operations include:

– independent creation of various objects of intellectual property;
– implementation of intellectual property into the authorized capital of the enterprise;
– purchase and sale of an enterprise (business);