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STATEMENT OF THE PROBLEM OF DYNAMIC SIMILARITY OF THE TRAWL SYSTEM

Abstract. Testing full-scale mechanical systems, such as trawl systems (bottom and midwater) is connected with great economic costs, therefore, it is advisable to carry out the study of dynamic processes on the models in laboratories. The paper describes special features, advantages and weak points of units for physical modelling fishing gears and processes (testing sites, experimental tanks, water flumes, water channels), which use two different modelling principles: modelling straight motion of a fishing tool model (towing) in still fluid and modelling reversed motion when a static model is washed by the moving water. There have been given detailed specifications and capacities of a model basin under Kaliningrad State Technical University, which is an instrument for studying model fishing gears and processes (seine hauling, trawl hauling, purse seine setting, etc.), as well as of a hydraulic channel in Kaliningrad, which is one of the largest construction of such type in the world. It is noted that during investigation of dynamic processes it is necessary to follow the rules of dynamic similarity. These rules have been developed at the Department of industrial fishing in Kaliningrad State Technical University. There has been determined the base scale for setting the problem of dynamic similarity of a trawl system, substantiation of which is primary in the model developing and testing at a selected unit. There was given the formula for taking the only one and correct decision in determining the base scale. In terms of the determined value of the base scale, there are calculated all the other scales of dynamic similarity given in the table of general scales of physical characteristics of hydrodynamic, ground dynamic and tribological processes, which occur in the trawl systems under dynamic similarity.

Key words: trawl system, physical modeling, rules of dynamic similarity.

Introduction

Physical modeling as a scientific method of obtaining knowledge about phenomena or processes of interest to us has a long history and is successfully applied in all fields of science. Indeed, by studying the dynamic processes occurring with technical units and aggregates of complex dynamic systems in full-scale conditions, one can obtain data on the functional dependencies connecting all the elements of the system, but do not establish what and how affects the characteristics of each element in separate. Testing of actual mechanical systems, such as trawl systems (bottom and mid-water) is associated with large economic costs. Therefore, it is more expedient to study dynamic processes on their models in laboratory conditions.

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Note that in the study of dynamic processes it is necessary to be guided by the dynamic similarity rules [1-3]. Listed in the table are the basic scales of the physical characteristics of hydrodynamic, soil-dynamic and tribological processes occurring in trawl systems under dynamic similarity.

In model testing of fishing gear, the features of their resistance are revealed; various theoretical and practical issues related to exploitation and increasing of their effectiveness are being solved. There are two principles of modeling. The first involves modeling of the direct movement of the fishing tool (towing) model moving in a stationary liquid. Such tests are carried out in special laboratories - experimental tanks. They can also be carried out in specially equipped open water reservoirs - test sites. The second principle is simulation of the reversed motion, when the stationary model is flowed by a stream of moving water.

Facilities for physical modeling of fishing gear and processes include test sites, experimental tanks, water channels and flow channels, wind tunnels and test stands.

Test sites for modeling fishing gear and processes are created on natural bodies of water (lakes, bays, reservoirs), which provides for very close to the actual model experiment conditions. On the one hand, this circumstance reduces the effect of the scale effect on the results of the model experiments and increases their reliability. On the other hand, it worsens experiment conditions, since in an open reservoir they are usually carried out in the presence of wind, agitated surface and other factors characteristic of actual conditions. A vivid example of the test site is Lake Vishtynetskoe which was the base of the Industrial Fishing Department of Kaliningrad Technical Institute of Fisheries until the 1990s.

Basic scales of the physical characteristics of hydrodynamic, soil-dynamic and tribological processes occurring in trawl systems under dynamic similarity

Scales of the physical characteristics		Conversion through scale C_l
Physical characteristics	**Representation**	
Geometry parameter (length, height, width, etc.)	C_l	C_l
Geometry parameter (square)	C_A	C_l^2
Geometry parameter (volume)	C_V	C_l^3
Geometry parameter (geometrical moment of inertia)	C_I	C_l^4
Mass	C_m	C_l^3
Time	C_t	$C_l^{5/4}$
Speed	C_v	$C_l^{-1/4}$
Force	C_R	$C_l^{3/2}$
Acceleration	C_w	$C_l^{-3/2}$
Bulk weight	C_γ	$C_l^{-3/2}$
Moment (rotary)	$C_{Мб}$	$C_l^{5/2}$
Density	C_ρ	1
Dynamic viscosity of water	C_μ	$C_l^{3/4}$
Kinematic viscosity of water	C_υ	$C_l^{3/4}$
Bending stiffness	C_{EI}	$C_l^{7/2}$
Material elasticity	C_E	$C_l^{-1/2}$
Pressure	C_p	$C_l^{-1/2}$
Rotation frequency	$C_{\omega б}$	$C_l^{-5/4}$
Oscillation frequency	C_f	$C_l^{-5/4}$
Tangential stress	C_σ	$C_l^{-1/2}$
Potential energy	C_U	$C_l^{5/2}$
Kinetic energy	C_{Tn}	$C_l^{5/2}$
Surface tension	$C_{\sigma п}$	$C_l^{1/2}$
Soil sliding	$C_{\tau гр}$	$C_l^{-1/2}$
Cohesion of soil	$C_{C\omega}$	$C_l^{-1/2}$
Normal load	$C_{\sigma гр}$	$C_l^{-1/2}$
Capacity	C_N	$C_l^{5/4}$
Hardness	$C_{НВ}$	$C_l^{-1/2}$
Angle	$C_\alpha = C_\varphi$	1
Uniformity	C_{Fo}	1
Resistance coefficient (counter force, side force)	C_k	1
Friction coefficient	$C_{\mu d}$	1
Relative elongation	C_ε	1

An undoubted advantage of test sites is a possibility to model not only the fishing gear, but also the fishery system as a whole, including a vessel and fishing gear. For example, when simulating a trawl system under the conditions of a test site, it is possible to provide geometric and force similarity of all its elements, including wires, otter boards, upper and ground gear, which is impossible to perform during experiments on laboratory facilities.

Advantages:

1. Minimum value of the scale effect.
2. Possibility for modeling of not only fishing gear but fishery system as a whole, including a vessel and fishing gear.

Disadvantages:

1. Rough experimental conditions, due to the presence of wind, agitated surface and other factors characteristic of full-scale conditions.
2. Expensive experiments.

Experimental tanks play an important role in the study of fishing gear and processes. Each experimental tank has a channel filled with water and equipped with a number of devices that bring the models into motion and perform all the necessary measurements (possibly with the recording and processing of the results), as well as a model shop. Currently, an experimental tank is often referred to as an institution that owns a tank itself (a channel with water). In this sense, the experimental tank is also referred to as a complex of other means that ensure experimentation. In addition to studying the resistance of water to the movement of various types of vessels (surface, submarine, dynamically supported) and in various conditions (in still water, in waves, in soundings), performance of fishing gear and other questions are being studied in tanks.

Two types of experimental tanks are distinguished in regards to bringing the model into motion, which usually also differ in their size: 1) tanks of gravitational type (small ones with a channel length of about 40-50 m), where the model is driven by the weight of the falling cargo; 2) basins of dynamometric type (large - with a channel length of about 1 km), where the model is driven by a special trolley moving along rails laid along the sides of the tank. In small tanks, the resistance is set (by means of the weight of the falling cargo), and the speed is measured; in large tanks, on the contrary, the speed of the trolley is set, and the resistance is measured. The choice of the type and size of the tank is determined by the tasks to be accomplished, financial possibilities and other considerations. The length of the pool should provide acceleration, setting the flow regime (double or triple length of the model), measuring when in motion at a constant speed and braking; acceleration at speeding-up and braking is limited. To eliminate the influence of the walls and bottom of the tank, its width and length should be 10 to 15 times larger than the width of the model.

After a long break KSTU has launched an experimental tank, where it is possible to conduct experiments to study the dynamics of trawl systems. The experimental tank of the Federal State Government-financed Educational Institution of Higher Education "Kaliningrad State Technical University" (FGGOU VO "KSTU") is a tool for researching fishing gear models and fishing processes (seine hauling, trawl hauling, setting of a purse seine, etc.), in particular - the scale effect (Fig. 1).

Advantages of the experimental tank are independence from seasonal and weather conditions and working area of large size. But it also has shortcomings: limited time for the experiment with the trawl construction, no underwater visualization of the processes occurring in the trawl system, etc. These limitations are superimposed on the dimensions of the future model of the trawl or other fishing gear and the magnitude of the scale effect.

The trolley, located on rails along the tank, is fixed to a steel cable, by means of which it moves. Subject to this, the trolley first accelerates, then it moves at a constant speed, and after it follows the process of braking.

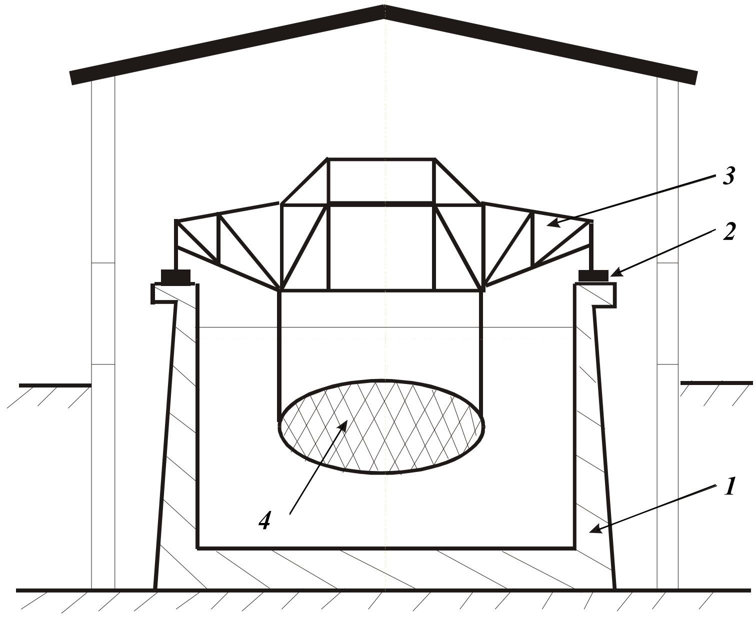
The values of acceleration and braking characteristics of the trolley are important in experiments with the model of trawl or other fishing gear, when a towing vehicle is used. Characteristics of the experimental tank at KSTU: length 52.0 m; width 7.0 m; depth 4.0 m.

In small tanks, an endless (ring) cable is attached to the model, thrown over two blocks located at the ends of the tank. At the end of the tank there is a doubled block; moreover, there is a cable attached to the model on a larger diameter pulley, and a cable on which a suspended falling weight is attached to a smaller diameter pulley. This allows for the reduction of the drop height of the load. The cargo can fall from a height (from a special tower) to the level of the basin, fall into the shaft, but more often its upper position is higher, and the lower one is below the tank level. At the beginning of the tank there is an accelerating device, giving the model its initial speed (otherwise the steady-state mode will be reached with a longer tank length), and at the end there is a braking gear. The trolley in the dynamometer type tanks is driven by an electric motor. There is a special device that allows the model to roll and at the same time to move translationally only with the trolley speed; it also provides measuring of the resistance and, if necessary, of other components of the hydrodynamic forces. The trolley is of the form of a truss bridge across the tank channel; at high test speeds it can be made covered.

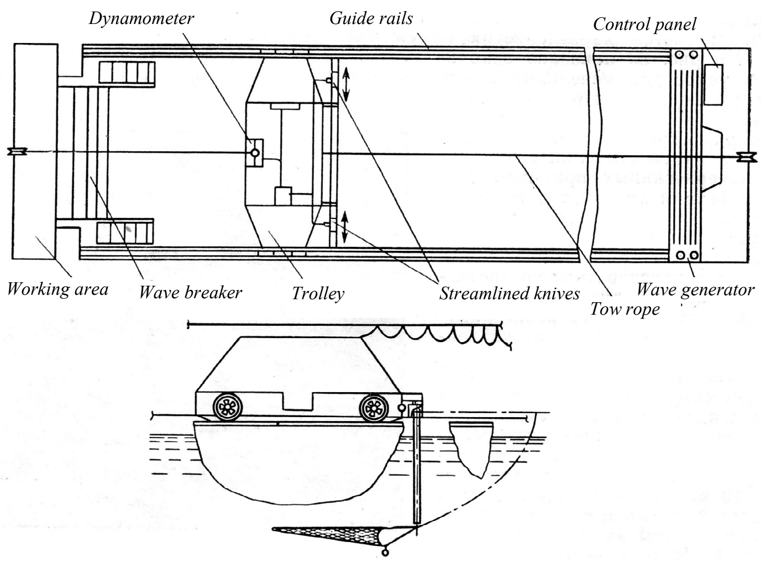
In order to reduce time between tests, wave breakers are used - devices that absorb the energy of waves formed as a result of moving models. Some of the tanks are equipped with wave generators - devices that create waves with specified characteristics. Waves can be regular, and in some tanks - irregular. Wave generators are needed to investigate the effect of waves on such fishing gear, such as purse seines, stationary nets, etc. Wave generators can be of various types; they create waves, performing forced oscillatory motions with a given amplitude and frequency. This makes it possible to investigate fishing gear and processes (hauling of a purse seine with allowance for waves) in rough sea with the required characteristics (increase in resistance, motions of various types of fishing vessels).

To simulate dynamic processes (bottom trawl hauling, bottom seine hauling), a winch is mounted on the trolley. So, for example, in the physical modeling of the bottom seine hauling process by the anchor method in the experimental tank at KSTU the following equipment was used: MIC-200 measuring complex, a double-drum winch, a strain gauge sensor, a power unit, a goniometer and a resistor.

More detailed information about the experimental tanks and their equipment can be found in specialized literature. To study controllability, there are rotational (round) tanks. The models rotate in them by means of a special rotary installation.



a



b

Fig. 1. Experimental tank of KSTU: *a* – cross-sectional drawing; *b* – views: top and side

Testing of fishing gear models can be carried out in other facilities (laboratories) - hydraulic channels and flow channel. The principle of reversed motion, when the model is standing still, and the flow of water is moving towards it, is used in a flow channel. Advantages of the channel are a relatively small size and the fact that the model, measuring equipment and experimentators are located in the research and experimental sector. The most serious drawback is that it is difficult to provide a uniform flow at the location of the model. This is associated with the so-called Du Bois paradox - under identical conditions the resistance in the flow channel is 10 to 15 percent higher than in the tank. The paradox can be explained by the inhomogeneity of the flow in the channel, the speed of which near the walls decreases, while in the model, on the contrary, it increases; moreover, radial velocities can occur. There are lots of hydraulic and flow channels in the world, but the biggest are:

1. Hydraulic channel SINTEFF in Hirtshals (Denmark).
2. Hydraulic channel of the University of Hull (England).
3. Hydraulic channel of the Central Aerohydrodynamic Institute in Saint Petersburg (Russia).
4. Hydraulic channel of "MariNPO" in Kaliningrad (Russia).
5. Hydraulic channel of the University of Tokyo (Japan).
6. Hydraulic channel of the University of Newfoundland (Canada).
7. Hydraulic channel of the Maritime College in Tasmania (Australia).
8. Hydraulic channel of IFREMER in Boulogne (France).

Development of fisheries in the open zone of the world ocean requires creation of highly effective instruments for industrial fishing, which is due to certain knowledge both in the field of biophysical features of the target fishery and engineering principles of designing gear. The latter, in turn, is impossible without the knowledge of hydrodynamic laws. Thus, creation of the necessary industrial fishing gear is closely related to the level of scientific achievements in hydrodynamics.

Specialists working in this field of science know what difficulties are caused by testing of fishing gear in the ocean. Experiments with physical models are carried out on specially equipped for this purpose test sites or on laboratory installations. In 1979, in Kaliningrad, a hydraulic channel was built and put into operation - a special laboratory-type facility for conducting experiments in the field of hydromechanics of industrial fishing gear.

Construction of the hydro canal lasted ten years, and today it is one of the largest buildings of this type in the world.

Its creation was preceded by special studies of the flow structure, which were conducted by SPA staff on a 1:10 scale model. As a result of the research, the design of the hydraulic channel was chosen, which ensured uneven flow in the whole range of velocities in the cross section of less than 1 and less than 3% along the length of the working area. The surface of the flow in the working area is even, without waves.

The degree of initial turbulence is 1.25%. In the hydraulic channel, 900 tons of water circulate at a speed of 0.05 to 3.5 m/s. Its hydraulic path is similar to wind tunnels with a spatial confusor (200 tons of water are held in vacuum). The spatial confusor (nozzle) with a large contraction ration allows to obtain plots of equal flow velocities practically throughout the entire working area. In addition, in the design of the hydraulic channel, various devices are used to improve the flow quality. Configuration of the return channel (diffuser) and other parts providing increased (relative to the total length) length of large cross-sectional areas allowed to reduce hydraulic losses to the minimum values and, thereby, to improve the quality factor of the hydraulic channel to 0.85, which doubles the similar coefficient at similar installations. The maximum power consumption of the electric drive is 140 kW (the set value is about 250 kW) at $v = 2.5$ m/s.

For observation, filming and photography, the channel is equipped with 18 rectangular illuminators 1.5 x 0.6 m in size, located in the side walls and bottom; in the front wall there is an inspection window with a size of 6 x 1.8 m (Fig. 2).

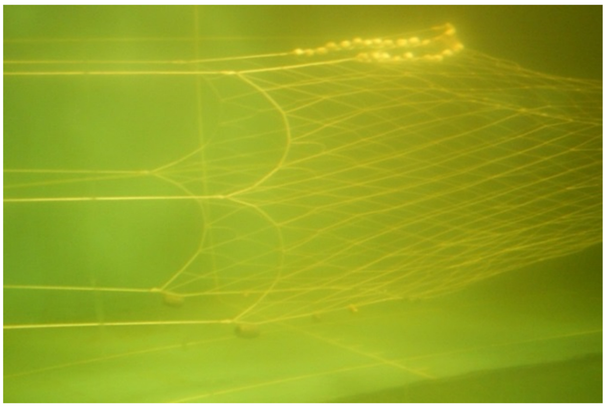


Fig. 2. Inspection window of the hydraulic channel of "MariNPO"
(physical modeling of the steady trawling process of the mid-water trawl)

Control equipment and flow control devices are on the control panel, located above the working area and providing a full view of the working space of the hydraulic channel. The latter is equipped with instruments and devices for measuring power and other parameters of the objects under investigation. A complex of trawl study facilities can measure the drag force and tightening force of the trawl net in the flow, spatial shape of the net, and tension force in its threads. In addition, it is possible to explore the dynamic processes of trawl management in depth. A special complex of units is designed to study hydrodynamic coefficients of the trawl boards and other attachments of the trawl, as well as the static stability of their movement.

In the hydraulic channel, it is possible to study pressure fields in the trawl, as well as conduct other research in the field of industrial fishing gear, fishing vessels, oceanologic equipment and ocean engineering. For registration and processing of experimental data, measuring and recording equipment and apparatus are used, including an automated system for collecting and processing information on a PC. To fix dynamic processes, a television complex of color image with a video recorder is used. The specified equipment is constantly updated or modernized.

Thirty years of experience in operating the hydraulic channel have shown that it is a universal installation in experimental hydromechanics and it can successfully compete with many other installations, including experimental tanks and even wind tunnels.

Today scientists carry out researches in the hydraulic channel to create new patterns for fishing trawlers; new trawls with improved parameters of the net cover, including those with a mirror (square) cell; unification of structural features of trawl boards with the purpose of increasing their maneuverability and hydrodynamic characteristics; work continues on improving the design of so-called acoustic trawls and many other research works.

Specifications of the hydraulic channel

Type ………………………………………….circulating vertical closed with an open working area
Dimensions, m…………………………………………………......................................34 x 9 x 12
Dimensions of the working area, m………………………………………………….………..…14 x 3 x 2
Height of the working area over the water surface, m ……………………….…….……….….…2
Water volume, m^3………………………………………………………………………...…….…..900
Maximum water velocity in the working area, m/s……………………………………….……......3.4
Input power of the driving unit, kW……………………………………………………..….…..…117
Installed power of the driving unit, kW……………………………………………...…………......250
Impeller diameter, m……………………………………………………………...……………...2.1
Impeller pump performance, m^3/s…………………………………….……………………….21.0

The main scale in formulation of the problem of dynamic similarity of the trawl system is C_l scale. Its substantiation is a paramount task when creating a model and conducting experiments on the selected unit. Thus, by the only correct decision in the choice of C_l scale can be done using the formula

$$C_l = \frac{L_w}{L_n},$$

where L_w – length of the working area of the experimental unit; L_n – length of the trawl system.

All other scales of similarity are calculated using a specified value of C_l (see table).

Conclusion

In the course of developing dynamic models of the trawl systems and carrying out experiments on the selected unit (experimental site, testing tank, water flume, water channel) the derived formula provides the only correct decision when choosing a base scale of physical characteristics of hydrological, ground dynamic and tribological processes occurring with trawl systems at dynamic similarity. At setting the task of dynamic similarity the substantiation of a base scale helps calculate all other similarity scales.

The offered design will provide improving new commercial charts of fishing trawlers; new trawls with advanced parameters of a net envelope; unified characteristics of trawl boards to increase their maneuvering and hydrodynamic parameters; improving acoustic trawls, as well as studying the processes of fisheries (seine hauling, trawl hauling, purse seine casting) and other research work.

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ПОСТАНОВКА ЗАДАЧИ ДИНАМИЧЕСКОГО ПОДОБИЯ ТРАЛОВОЙ СИСТЕМЫ

Испытания натурных механических систем, каковыми являются траловые системы (донные и разноглубинные), сопряжены с большими экономическими затратами, поэтому исследования динамических процессов целесообразней вести на их моделях в лабораторных условиях. Описаны особенности, достоинства и недостатки установок для физического моделирования орудий и процессов рыболовства (полигоны, опытовые бассейны, гидролотки, гидроканалы), в которых используются два различных принципа моделирования: моделирование прямого движения модели орудия рыболовства (буксировки), движущейся в неподвижной жидкости, и моделирование обращенного движения, когда неподвижная модель обтекается потоком движущейся воды. Детально описаны характеристики и возможности опытового бассейна при Калининградском государственном техническом университете, являющегося инструментом для исследования моделей орудий лова и процессов рыболовства (выборка невода, выборка трала, замет кошелькового невода и др.), и гидроканала в г. Калининграде – одного из крупнейших сооружений подобного типа в мире. Отмечается, что при исследовании динамических процессов необходимо руководствоваться правилами динамического подобия. Такие правила разработаны на кафедре промышленного рыболовства Калининградского государственного технического университета. Определен главный масштаб при постановке задачи динамического подобия траловой системы, обоснование которого и является первостепенным при создании модели и проведении экспериментов на выбранной установке. Приведена формула, позволяющая принять единственно правильное решение при выборе главного масштаба. Исходя из определенного значения главного масштаба рассчитываются все остальные масштабы подобия, приведенные в таблице основных масштабов физических характеристик гидродинамических, грунтодинамических и трибологических процессов, которые протекают в траловых системах при динамическом подобии.

Ключевые слова: траловая система, физическое моделирование, правила динамического подобия.

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