**Kostyantyn
S. Trunin**
Трунін
Костянтин
Станіславович

УДК 531,391: 627,713

THE THREE-DIMENSIONAL MOTION OF MARINE TETHERED SYSTEM AT EXAMPLE BUOY OF NEUTRAL FLOATING

ПРОСТОРОВИЙ РУХ МОРСЬКИХ ПРИВ'ЯЗНИХ СИСТЕМ
НА ПРИКЛАДІ БУІВ НЕЙТРАЛЬНОЇ ПЛАВУЧОСТІ

DOI [https://doi.org/10.15589/smi2019.1\(11\).3](https://doi.org/10.15589/smi2019.1(11).3)

Kostyantyn S. Trunin

Трунін Костянтин Станіславович

канд. техн. наук, доц.

trunin.konstantin.stanislaw@gmail.com

ORCID: 0000-0001-6345-6257

National University of Shipbuilding, Mykolayiv

Національний університет кораблебудування, м. Миколаїв

Abstract. The floating complexes – buoys, floating freely (drifting) or tethering cable (oceanographic, neutral buoyancy, special, etc.) can be considered one of the Marine tethered system class (MTS), having in its composition a flexible links (FL). Previously, the problem of designing a buoy of neutral floating (BNF) are treated as one-criterion problem when all other requirements can be expressed in the form of various quantitative restrictions. The aim of the study is to test the performance and versatility of the model created by the dynamics of the algorithm and computer simulation of the dynamics MTS program with FL as an example of the BNF. The examples of the use of model MTS speakers FL: – small buoy without the float, current in the a 45°, seaways, the rock 10 m, in this case takes place on an open construction with 15.77 sec; – small buoy and the load, current in the a 45°, seaways, the rock 10 m, the load pulls a small buoy and does not give him the opportunity to move freely. FL destruction does not occur; – small buoy and the load, current in the a 45°, seaways, the rock 10 m, slow speed of CV. The diagrams in column 2 of Table. 4 allow to observe the configuration parameters of the system in real time. Watching the changes of the parameters, it can be seen that under agitation and the presence of heavy load power CV. Not enough to keep on course (see the parameters for 3 seconds and 250 seconds). FL does not apply to underwater obstacles (rocks), as CV UTS system removes from it. In column 3 of Table. 4. On account of the excitement and impact load that is in the middle of the farm, produced a surge in FL that can be seen in charts. FL failure, however, does not occur. Created a computer program describing the dynamics of the MTS with FL allows us to apply it also to describe the movement of the BNF at anchor. The developed mathematical model and algorithm of dynamics FL of MTS realized a computer program describing the dynamics FL of MTS, MTS enables project, having in its composition, better and more quickly to design almost all MTS classes in various modes of operation and maneuvering.

Key words: Marine tethered system (MTS), flexible links (FL), buoy of neutral floating (BNF), three dimension of motion, regime of motion.

Анотація. Своєрідні плавучі комплекси – буї, що вільно плавають (дрейфуючі) або утримувані тросом (океанографічні, нейтральної плавучості, спеціальні і т.п.) можна розглядати як один із класів морських прив'язних систем (МПС), що мають у своєму складі гнучкий зв'язок (ГЗ). Раніше завдання проектування буїв нейтральної плавучості (БНП) розглядали як однокритеріальне завдання, коли всі інші вимоги можуть бути виражені у формі тих або інших кількісних обмежень. Метою дослідження є перевірка працездатності й універсальності створені моделі динаміки, алгоритму й комп'ютерної програми моделювання динаміки МПС із ГЗ на прикладі БНП. Розглянуто приклади використання моделі динаміки МПС із ГЗ: – малий буй без поплавця, плін під 45°, хвилювання, скеля 10 м, у цьому випадку має місце обрив ГЗ на 15,77 с; – буй малий і вантаж, плін під 45°, хвилювання, скеля 10 м, вантаж відтягає малий буй і не дає йому можливості вільно переміщатися. На 103 с ГЗ не торкається підводної перешкоди (скелі), притискає ГЗ до скелі, у результаті чого ГЗ сковує по ній. Руйнування ГЗ не відбувається. – буй малий і вантаж, плін під 45°, хвилювання, скеля 10 м, малий хід СН. Діаграми в 2 стовпці табл. 4 дають змогу спостерігати за зміною параметрів системи в реальному масштабі часу. Спостерігаючи за змінами параметрів, можна помітити, що в умовах хвилювання й наявності на ГЗ вантажу потужності СН не вистачає для втримання на курсі. ГЗ не торкається підводної перешкоди (скелі), тому що СН відводить ПБС систему від неї. Завдяки хвилюванню і впливу вантажу, що перебуває всередині ГЗ, утворюються пульсації в ГЗ, які можна бачити на діаграмах. Руйнування ГЗ не відбувається. Створена комп'ютерна програма опису динаміки МПС із ГЗ дає змогу застосувати її також і для

опису процесу руху БНП на якорі. Розроблені математична модель й алгоритм динаміки ГЗ МПС, реалізовані у вигляді комп'ютерної моделі опису динаміки ГЗ МПС, дають змогу проєктантові МПС, що мають у своєму складі ГЗ, більш якісно й оперативно проєктувати практично всі класи МПС на різних режимах експлуатації й маневрування.

Ключові слова: морська прив'язна система (МПС), гнучкий зв'язок (ГЗ), буй нейтральної плавучості (БНП), просторовий рух, режим руху.

References

- [1] Trunin, K.S. (2017). Uravneniya dynamiki elementa gibkoy svyazy morskoy privjaznoy systemy [Equations of dynamics of flexible links of Marine tethered system]. *Zb. nauk. prats of NUK*. № 1(468), 18–25 [in Russian].
- [2] Trunin, K.S. (2017). Matematicheskaya model dvukh svyazannykh elementov gibkoy svyazy morskoy privjaznoy systemy [The mathematical model of two connection elements of flexible links of Marine tethered system]. *Zb. nauk. prats of NUK*. № 2(469). 3–10 [in Russian].
- [3] Trunin, K.S. (2017). Dynamika morskoy privjaznoy systemy s gibkoy svyazju [The dynamics of Marine tethered system with flexible link]. *Zb. nauk. prats of NUK*. № 3(470). 3–10 [in Russian].
- [4] Trunin, K.S. (2014). Algoritm modelirovaniya dinamiki morskoy privjaznoy sistemy s gibkoy svyazju [Algorithm of modelling of Marine lash system dynamics with flexible links]. *Proceedings of the All-Ukrainian Scientific and Technical Conference with international participation: Podvodnatekhnikha i tekhnologiya, in 2 part, 1 part*. Mykolayv, NUOS, 36–42 [in Russian].
- [5] Trunin K.S. (2017). Kompyuternaya model dinamiki morskoy privjaznoy sistemy s gibkoy svyazju [Computer model of MTS with FL]. *Zb. nauk. prats of NUK*. № 4(471). 3–13 [in Russian].
- [6] Berto, G.O. (1979). *Okeanograficheskie bui: per. s angl.* [Ocean's buoys]. Leningrad, Sudostroenie [in Russian].
- [7] Greku, R.Kh., Ostretsov, G.A., Puchkin, V.A., Cherkasova, A.V. (1978). Dreyfuyushchie bui dlya issledovaniya techeniy v okeane [Drift buoys for research of ocean currents]. Sevastopol, MGI. Preprint № 2, 18 p. [in Russian].
- [8] Ikonnikov, I.B., Gavrilov, V.M., Puzyrev, G.V. (1992). Podvodnie buksiruemye sistemi bui neytralnoy plavuchesty [Underwater towed systems and buoys of neutral floating]. Sanct-Petersburg, Sudostroenie [in Russian].
- [9] Tarasyuk, Yu.F. (1980). Mezhdunarodnie okeanograficheskie ekspeditsii (pp. 30–40). [International oceanographic expeditions]. *Man, sea, techniques: Collection*. Leningrad, Sudostroenie [in Russian].
- [10] Zhmur, V.I. (2013). Zachem voda techyet v vode? [What for water leaks in the water?] *Populyarnaya mekhanika*. № 7 (129). 38–42 [in Russian].
- [11] Gayskiy, V.A., Artyemov, Ju.G., Blinkov, V.A. (1987). Avtomatizirovannye sistemy s buksiruemymi priborami v okeanologicheskikh issledovaniyakh [Automated systems with towing instruments in the oceanographic researches] Kiev, Nauk. dumka [in Russian].
- [12] Kalyukh, Ju.I., Gorban, V.A. (1986). Kvazistaticheskiy analiz pritoplennykh buykovykh okeanograficheskikh sistem [Quasi-static analysis of half-drown buoy's oceanographic systems] *Gidromekhanika USSR*. Issue. 53, Kiev, 72–76 [in Russian].
- [13] Kenni, Dj.E. (1977). Tekhnika osvoeniya morskikh glubin [The bring equipment of sea depths]. Leningrad, Sudostroenie [in Russian].
- [14] Korolyev, V.I. (1978). Trekhmernaya zadacha o dvizhenii sistemy tel v potoke [Three-dimensional problem about motion of bodies system in the flow]. *Gidromekhanika*. Issue. 38. Kiev, Naukova dumka, 59–76 [in Russian].
- [15] Korolyev, V.I., Lemesko, E.A. (1978). Ravnovesie sistemy gibkaya nit – telo v trekhmernom potoke zhidkosti [The balance of flexible filament – body system in the three-dimensional flow liquid]. *Gidromekhanika*. Issue. 38. Kiev, Naukova dumka. 108–112 [in Russian].
- [16] Kuvshinov, G.E., Naumov, L.A., Chupina, K.V. (2005). Sistemy upravleniya glubinoi pogruzeniya buksiruemyykh objektov: monografiya [Control systems of diving of towed objects]. Vladivostok, Dalnauka [in Russian].
- [17] Kulmach, P.P. (1980). Yakornye sistemy uderzhaniya plavuchikh objektov (Voprosy stiki i dinamiki plavuchikh ssoruzheniy na yakoryakh) [Anchor systems keep down of floating objects]. Leningrad, Sudostroenie [in Russian].
- [18] Vinogradov, N.I., Gutman, M.L., Lev, I.G., Nisnevich, M.Z. (2000). Privyaznie podvodnie sistemi. Prikladnie zadachi statiki i dinamiki [Tethered marine system. Trimmings problems of static and dynamic] : Izd-vo S.-Petersb. un-ta [in Russian].
- [19] Printsipy postroeniya tekhnicheskikh sredstv issledovaniya okeana (1982). [Creation principles of research techniques facilities of ocean] / Red. V.S. Jastrebov. Moskva, Nauka [in Russian].
- [20] Samokhodnie neobitaemye podvodnie apparaty (1986). [Automotive submersible non manned vehicles]. Red. I.B. Ikonnikov. Leningrad, Sudostroenie [in Russian].
- [21] Shekhvatov B.V. (1979). Okeanograficheskie bui i buykovye laboratorii (pp. 183–204) [Oceanographic buoys and buoy's laboratories]. *Research problems and bring of World Ocean* / Red. A.I. Voznesenskiy. Leningrad, Sudostroenie [in Russian].

- [22] Jastrebov, V.S. (1986). *Metody i tekhnicheskie sredstva okeanologii* [Methods and techniques facilities of oceanology]. Leningrad : Gidrometeoizdat [in Russian].
- [23] Ageev, M.D., Kasatkin, B.A., Kiselev, L.V. (1981). *Avtomaticheskie podvodnie apparaty* [Automatic submersible vehicles]. Leningrad, Sudostroenie, 224 p. [in Russian].
- [24] Bugaenko, B.A., Gal, A.F. (2012). Kachka na neregulyarnom volnenii plavuchikh objektov, zakrepyennykh na predvaritelno natanutykh gibkikh svyazyakh [Oscillating motions of floating objects which made fast by precede tensioned flexible links on the irregular waves]. *Zbirnyk naukovykh prats NUK named adm. Makarov*. № 1. Mykolayiv, 38–42 [in Russian].
- [25] Dmitriev, A.N. (1978). *Proektirovanie podvodnykh apparatov* [Desining of submersible vehicles]. Leningrad, Sudostroenie [in Russian].
- [26] Lavrentiev, M.A., Shabot, B.V. (1977). *Problemy gidromekhaniki i ikh matematicheskie modely*. [Problems pf gydromekhanics and their mathematical models]. Moskva, Nauka [in Russian].
- [27] Lobanov, V.A. (1983). *Spravochnik po tekhnike osvoeniya shelfa* [Reference book about bring equipment of shelf]. Leningrad, Sudostroenie [in Russian].

Problem statement. We have studied the existing marine tethered system (MTS) [3] having in their composition a flexible links (FL). A mathematical model of the dynamics of MTS with the FL, which allows to describe the significant movement of the FL in the absolute coordinate system [1; 2], and used to develop an algorithm for calculating the dynamics of FL with its large displacements [45], in the form of realized computer's program [5].

However, there is another class of MTS having in its composition FL [6–9], – a kind of floating complexes – buoys, floating freely (drifting) or tethering cable (oceanographic, neutral buoyancy, special, etc.).

I.B. Ikonnikov in the preface to the book G.O. Ber to [3, p. 5] notes that buoys – surface and recessed, free-drifting and anchored, equipped with modern electronics and long-distance transmission of information – can be quite thoroughly inspect the entire thickness of the ocean long time intervals. In the ocean, there was a set of large and fairly sophisticated buoy stations operating in deep water and perform a variety of functions.

Thus, d. F-m. n., head of Laboratory of the Institute of Oceanology of marine currents them named P.P. Shirshov Rastian Academy of Sciences Vladimir Zhmur says [8, p. 41] that one of the main tools for studying ocean currents began to develop since the late 1990-s, a global network of robotic floats floats ARGO variable buoyancy – the main modern tool of studying ocean currents. Installed from ships or buoys aircraft cover a network of almost the entire world's oceans. Buoys are evenly distributed throughout the world's oceans except the Arctic zone, with a pitch of about 300 km. Originally planned amount in 3000 buoys was reached in 2007 year, and now their number is constantly increasing. A characteristic feature of the robotic float ARGO – its variable buoyancy. Bui works in cycles of ten days. Most of the time (nine days), it is located at a depth of about 1000 m and then briefly lowered to 2000 m, and then pops up to during the day transfer to the satellite data collected over the watch. At various depths on the surface buoy measures the density, electrical conductivity, optical properties, and even water.

In the 1980-s, the task of designing the BNF is considered as a one-criterion problem when all other re-

quirements can be expressed in the form of certain quantitative restrictions [8, p. 122].

In order to test the universality developed a mathematical model and algorithm dynamics of the MTS with FL implemented as computer's program of description of dynamics MTS with FL, use the resulting model to describe the dynamics of the BNF.

Latest research and publication analysis. Buoy of neutral floating (BNF) – Automatic self-propelled autonomous underwater vehicles, in which as a payload installed various complexes research equipment [8, p. 118]. They are sometimes called neutral buoyancy floats (NBF) – stand-alone media research equipment, rather than having automatic means of buoyancy control.

The emergence of the NBF, and then BNF was due to the need to:

- improve the accuracy of sonar and gravity measurements by eliminating complex electromechanical coupling of the instrument to the vessel in the form of a cable-rope on which inevitably disturbing influences from the vessel;

- increasing duration measurements (especially when studying underwater currents, internal waves, ocean and other large-scale vortex phenomena in the ocean) without using escort vessel.

In the book, G.J. Berthod [6, p. 7] the set of theoretical and practical information needed for the design and selection of core elements buoy complexes. These elements include proper buoys (so-called body with limited movement) surface and buried, buoy line (retaining cables), the armature and the auxiliary devices and equipment. These elements are combined in the system of the buoy. It also considered the statics and dynamics of the submerged anchor wires. The statics are considered constant load and resultant buoy line configuration. First studied simplest model so nazyvaemyy “closed solutions” (“chain line”) is then introduced cable function. Finally, a programmed method for calculating the flat and spatial options are discussed in detail. The buoy line dynamics are investigated linear models. In the first model, the cable is regarded as an elastic continuous medium. In this case, the tension and the offset value determined by solving the wave equation with a respective granichnymy conditions. In the second model of the ca-

ble it is represented as a finite number of discrete masses interconnected by spring elements. In conclusion of this part are methods of solutions of systems with several degrees of freedom. Also considered Bueva classification, methods of their design, particularly the design, selection buoyancy materials, etc. In conclusion of this part are methods of solutions of systems with several degrees of freedom. Also considered Bueva classification, methods of their design, particularly the design, selection buoyancy materials, etc. In conclusion of this part are methods of solutions of systems with several degrees of freedom.

The literature [8; 11–17; 18–22] accumulated a large amount of theoretical and experimental data on the hydrodynamic resistance of the cylindrical bodies yaky can be used in the design of BNF. For the design of specific BNF, as noted I.B. Ikonnikov, V.M. Gavrilov and G.V. Puzyrev available data need to be interpreted correctly [8, p. 124–125]. Analysis of the literature [8, p. 128] has shown that static calculations methodology NBF has much in common with static unmanaged submersible vehicle (SV) and submarine (S).

Fig. 1 is an example buoy spanned from station-mentioned buoy line belongs Woods Houls oceanographic Institute) [6, p. 114].

Fig. 1. Floating is fixed on the basis of the still submerged (but may float and sink), stationary (fixed on the basis of fixed underwater anchor) $V_{BNF} = 0$

When the development of the shelf is often necessary to transfer significant power through underwater cables. The company “Simplex Valle End Cable” (UK) has developed the transmission system at 35 kV [27, p. 238]. The system consists of an oil vessel, equipped with a generator; buoy, connected to the bottom by a hinged rack; intermediate underwater buoy, supporting cable

and production platform. The vessel is permanently connected to the buoy mounted on a hinge post and performing raid berth function.

Fig. 2 shows one anchor’s moorings buoy station of Woods Houls Oceanographic Institute at the bottom of the buoy [6, p. 121].

Fig. 2. Single Anchor Leg moorings Woods Houls Oceanographic Institute at the bottom of the buoy [3, p. 116]:

1 – radio beacon;
2 – The flashing light,
3 – Spherical glass buoyancy;
4 – a current meter;
5 – acoustic isolator;
6 – anchor

Fig. 3. With the underwater buoy station auxiliary buoy [3, p. 116]:

1 – vertical cylindrical buoy with a spotlight transmitter and meteorological sensors;
2 – electronic block;
3 – Floating half rigidity;
4 – the universal joint;
5 – auxiliary underwater buoy;
6 – a metal cable;
7 – chain;
8 – anchor

Fig. 3 shows French underwater buoy station with auxiliary buoy.

In [12, p. 72–76] a mathematical model of autonomous submerged buoy station (ASBS), by which on the basis of experimental data on the relative flow velocity at some horizons at discrete instants of time expected to reverse geometry ASBS at these times and to estimate the distortion It introduced its own motion ASBS readings of flow rate.

Fig. 4 shows an example submerged buoy system is distributed throughout the buoy line buoyancy elements (hollow glass spheres [6, p. 208]. As you can see, their design can be rather complicated and cumbersome.

Methods, object and subject of research. We used the following methods: analysis (selection of the object and subject of the study), the synthesis of (part object, features, properties), structuring (structural MTS construction with FL allows the use of combination where the elements can change place in the structure and change the qualitative aspect of the object), synthesis (in a primary generalizations can serve as part of MTS as a part of Tethered Systems (TS), and then releasing the other TS – Underwater Tethered Systems (UTeS), Submerged Towed Systems (STS), simulation (study – original object by creating and examining its copy (model).

As the empirical methods used: observation (fixation of the observed object – produced under the supervision of the information was recorded, systematized on the various observations of the same object, carried out at different times), experience (previous studies), experiments (using the computer's model of distribution of dynamics MTS with FL).

Fig. 4. Typical submerged buoy system is distributed throughout the buoy line buoyancy elements (hollow glass spheres) [3, p. 208]

Subject of study a spatial movement on MTS an example BNF.

Object of study is a MTS construction with FL (for example BNF).

The article aim. The aim of article is to verify the functionality and versatility of the dynamics model created by the dynamics of the algorithm and computer program simulation of the dynamics distribution of MTS with FL as an example of the BNF that perform calculations BNF dynamics.

The basic material (results). As noted G.O. Berto [6, p. 9], the analysis of the forces produced by the particles and the fluid acting on the floating body with limited movement, and their moments are important for the proper design of floating structures, and a choice of ways to retain them at some point in the ocean. It is assumed that the forces due to currents and winds are constant and

forces being called excitement, change over time. The excitement in the ocean has a strong effect on the behavior of the anchor cables, retaining the buoy station [6, p. 80]. Examination of responses to these impacts ropes to determine the value and character of the distribution of dynamic loads, as well as to clarify the conditions of resonance.

When choosing the type and size of elements dynamic loads should be read in conjunction with the static [8]. Resonant effects and they cause significant fluctuations in the cable can create enormous peak loads. As a result, there is a threat of serious damage. To study the dynamics of the buoy line used two fundamentally different approaches: buoy line is regarded as a continuous elastic thread and as a series of discrete, freely oscillating spring-mass.

In general, the uncontrolled movement of the BNF dynamics problems can be attributed to the dynamics of a compressible body moving in a compressible stratified fluid perturbed [8, p. 16]. Because BNF stabilization zone depths in the passive mode does not exceed a few tens of meters, it is generally considered linear density stratification field and (or) the temperature in the direction of the gravity vector. Dynamics uncontrolled movement BNF examines the motion of the buoy under the influence of various interfering process apparatus [8, p. 126]. The reliability of mathematical modeling motion processes will be the higher, the more precisely the original motion equation BNF.

On the basis of the developed mathematical model of the dynamics of the MTS with the FL [1–3], defines the system of equations describing the dynamics of the FL element [4] as a result of external forces on it and stretching reactions twists and turns. The algorithm FL dynamics modeling allows you to perform calculations of the dynamics of FL of the MTS, and later go on to develop a computer program, describing the dynamics of MTS with the FL. Using this computer model to describe the dynamics of the BNF. The obtained model instead of Carrier Vehicle (CV) use BNF instead of SV – anchor (A).

Consider the examples of the MTS dynamics model with FL:

- 1). small buoy without the float, current in the a 45°, seaways, the rock 10 m;
- 2). small buoy and the load, current in the a 45°, seaways, the rock 10 m;
- 3). small buoy and the load, current in the a 45°, seaways, the rock 10 m, slow speed of CV.

Case 1. Small buoy without the float, current in the a 45°, seaways, the rock 10 m. In Fig. 5 is a view of the working window BNF dynamics simulation program after data input.

Working window of the program contains a window for setting the values of parameters and MPS 58 4 algorithm parameters. The point here is these windows jot down the name of the parameter and dimension. Number of HS elements defines simulation accuracy and time-consuming to perform calculations. dynamics simulation time conditionally accepted 250. Step visualization of simulation results determines the frequency of

update diagrams in the working window, and write the results to files on the hard disk.

Number of construction elements of FL made 20 elements, length of one element is 5 meters. Construction parameters: initial construction length of 100 m; heavy initial diameter of 14 mm; density per unit length heavy 0.15386 kg/m; Young's modulus of the material construction $9,55 \cdot 10^8$ Pa; allowable tensile strength of the FL $2 \cdot 10^4$ N; tangential drag coefficient construction of FL 0.025; normal drag coefficient farm of FL 1.8; heavy obstacle of FL in the friction coefficient 0.5.

Two groups of eight parameters of each, determine the characteristics of BNF and the A (Table 1).

Table 1. Parameters BNF and A

№	Specifications	BNP	A
1	length	2 m	1 m
2	width	2 m	0.4 m
3	draft	1 m	0.4
4	displacement	1,000 kg	150 kg
5	buoyancy	3	- 0.1
6	resistance coefficient	2.6	2
7	stationary time	0 sec	1000

Stationary means time from the beginning of the MTS dynamics simulations during which BNP or A remain stationary in the sea plane vertically movable BNP and I in the stationary time of 0 (absent). Courant number 0.3.

Initial construction coordinates are determined by three coordinates and BNF and A: initial X-coordinate of BNF 60 m; BNF starting coordinate

of Y 0 m; initial coordinate BNF at Z is 0 m; initial coordinate of A the X 0 m; starting coordinate of A Y 0 m; A for initial coordinate Z 80 m. The initial time is shaped construction unstretched straight line (tensile force zero) joining the points with coordinates BNF and A. If the initial length heavy greater than the distance between BNF and A, then the program algorithm automatically changes the coordinates of the position A am in the H0Y plane, and without changing the set coordinates of its position on the Z, and then, to the top of the simulation dynamics MTS moves A initially specified point. In this case, if the specified coordinate A in the Z axis is greater than the minimum depth of the sea.

Sea water is considered incompressible and has a density of $1,000 \text{ kg/m}^3$. Characteristics of steady seaways at the sea surface is determined by two parameters: a wind speed of 10 m/s; wind direction angle of 0 deg. A homogeneous volume of sea water area characterized by three projections for its speed on the coordinate axes: $V_x = 1 \text{ m/s}$; $V_y = 1 \text{ m/s}$; $V_z = 0 \text{ m/s}$. Relief bottom waters characterized by three parameters: the mean water depth of 80 m; amplitude changing water depth 30 m; coordinate (X-axis) changes in water depth of 10 m. The water depth is changed stepwise by an amount predetermined amplitude constant along lines parallel to the Y axis, the position of which in the X coordinate axis is determined by the depth of the sea changes. If the water depth decreases, the amplitude of the negative, otherwise – it is positive. At predetermined points of time (a predetermined pitch visualizing) occurs recording generalized coordinates heavy and BNF nodes as well as heavy tensile forces at the nodes of its elements in the file system. These files are available for data analysis after the com-

FILUM

Fig. 5. View dynamics simulation program working window of the dynamics of the BNF after entering the initial data for the case 1

Table 2. Parameters of the model as a function of time (case 1)

time	The parameters in the coordinate system	FL options
2 sec.
7 sec.
13 sec.
15.77 sec.

pletion of the work program). The recorded parameters are given in Table. 2.

The simulation results are presented graphically in seven diagrams at a given time, which shows in the window next to the diagram (see. Fig. 4). These moments are determined at intervals of time through it image change occurs in the diagrams, and set the parameter “visualizing step, sec”. In this case, the three charts show the spatial arrangement of the BNF, FL and A projected on the plane X0Z, Y0Z and X0Y Cartesian coordinate system.

The fourth diagram shows the distribution of heavy stretching forces along its length (coordinate S) (shown in the second column of Table. 2). In this case, the three charts show the spatial arrangement of the BNF, FL and A projected on the plane X0Z, Y0Z and X0Y Cartesian coordinate system. The fourth diagram shows the distribution of heavy stretching forces along its length (coordinate S) (shown in the second column of Table. 2). In this case, the three charts show the spatial arrangement of the BNF, FL and A projected on the plane X0Z, Y0Z

and XOY Cartesian coordinate system. The fourth diagram shows the distribution of heavy stretching forces along its length FL (coordinate S) (shown in the second column of Table. 2).

In the first three diagrams, coordinate range varies continuously adapting to MTS location at the current time, however for purposes of clarity, the fifth diagram coordinates X and Y vary only within ± 100 meters.

On the sixth chart positioning data about the change in time FL tension forces acting on the BNF and A. On the seventh diagram shows the change in the speed of BNF (natural speed A is 0) during its movement. In the process of modeling the dynamics of BNF force FL stretching exceeded the permissible value to 15.77 s (FL rupture occurred), the program is finalized and put on your window message "Break FL !!!".

Case 2. Consider the case: small buoy and the load, current in the a 45° , seaways, the rock 10 m. Such a scheme is shown in Fig. 6 [26, p. 124]. Buoyancy maintained taut rope anchor portion in the anchor, the force of gravity on the portion of the buoy station is not transmitted. Rope hanging free, steel ropes. As supports used anchoring ships or gravity anchors. Vertical load from the force of gravity the anchor rope portion receives the buoy stations. Buoyancy maintained taut rope anchor portion in the anchor, the force of gravity on the portion of the buoy station is not transmitted.

Fig. 7 shows a fragment of the dynamics simulation software working window floating buoy after data input in this case.

Table. 3 in this case shows the spatial location of the BNF, FL and A, FL settings for some of the stages dynamics simulation time conditionally accepted 250.

In the first column of Table. 3 shows the time dynamics simulation (chosen randomly). The last point was chosen time 231 sec, as further to point 250. characteristics do not differ. The diagrams in column 2 of Table. 3 allow to observe the configuration parameters of the system in real time.

As you can see, the weight pulls a small buoy and does not give him the opportunity to move freely. At 103 sec FL cartridges underwater obstacles (rocks), presses the FL to the rock, resulting in a FL slides on it. FL destruction does not occur, as in the previous case.

Case 3. Consider the case: small buoy and the load, current in the a 45° , seaways, the rock 10 m, slow speed of CV. As an example diagram (Fig. 8) [3].

Fig. 9 shows a fragment of the working dynamics simulation program window dynamics floating buoy after data input for the

Table. 4 in this case shows the spatial location of the CV, BNF, FL and A, FL settings for some of the stages. Dynamics simulation time conditionally accepted 250.

In the first column of Table. 4 shows the time dynamics simulation (arbitrarily chosen) which conditionally accepted 250. The last point parameters are indications for the time 250 seconds. The diagrams in column 2 of Table. 4 allow to observe the configuration parameters of the system in real time. The velocity of a small CV (CV

Fig. 6. Anchor Systems Buoy's stations with attached to the buoyancy relations to greater depths

FILUM

2	длина СН, м	1	длина ПА, м
2	ширина СН, м	0.4	ширина ПА, м
1	осадка СН, м	0.4	осадка ПА, м
1000	водоизмещение СН, кг	150	водоизмещение ПА, кг
3	Плавучесть СН	-0.1	Плавучесть ПА
2.6	коэф. сопр. СН	2	коэф. сопр. ПА
0	стац. время СН, с	1000	стац. время ПА, с
Возможность вертикал. перемещ. в стац. время (1-да, 0-нет)			
0	СН	0	ПА
20	количество элементов ГС	0	ампл. верт. кол. СН, м
0.3	число Куранта	0	част. верт. кол. СН, Гц
250	время моделирования, с		
100	длина ГС, м	0	Нач. коорд. ПА по X, м
14	диаметр ГС, мм	0	Нач. коорд. ПА по Y, м
0.15386	масса ГС, кг/м	80	Нач. коорд. ПА по Z, м
9.55e8	модуль Юнга ГС, Па	-60	Нач. коорд. СН по X, м
2e4	сила разрыва ГС, Н	0	Нач. коорд. СН по Y, м
0.025	тангенц. коэф. сопрот. ГС	0	Нач. коорд. СН по Z, м
1.8	норм. коэф. сопрот. ГС	1	Vx, м/с
0.5	коэф. трения ГС о преграду	1	Vy, м/с
		0	Vz, м/с
1000	плотность воды, кг/м3	0	Gx_ПА, Н
10	скорость ветра, м/с	0	Gy_ПА, Н
0	направление ветра, град	0	Gz_ПА, Н
80	средняя глб. моря, м	50	Водоизмещение поплавка, кг
-30	ампл. изм. глб. моря, м	-0.5	Плавучесть поплавка
10	коорд. изм. глб. моря, м	50	Расст. от коренного конца ГС до поплавка

Fig. 7. Fragment working dynamics simulation program window dynamics floating buoy after data input to the case 2

1000 W engine power), however, watching the changes in the parameters, it can be seen that under agitation and the presence of heavy load power CV. Not enough to keep on course (see the parameters for 3 seconds and 250 seconds). FL does not apply to underwater obstacles (rocks),

Table 3. Parameters of the model as a function of time (case 2)

Time	The parameters in the coordinate system	FL options
1	2	3
9 sec.
15 sec.
55 sec.
75 sec.

End Table 3

1	2	3
103 sec.
123 sec.
171 sec.
231 sec.

Table 4. Parameters of the model as a function of time (case 3)

Time	The parameters in the coordinate system	FL options
1	2	3
3 sec.
8 sec.
23 sec.
62 sec.

End Tables 4

as CV removes system UTeS from it. In column 3 of Table. 4 The parameters (top to bottom): T_{CV} – tension force on the driving end of the heavy construction, N; N_{CV} – CV motor power, W; V_{CV} – CV velocity, m/s. On account of the excitement and impact load that is in the middle of the farm, pulsation generated in construction, which can be seen en diagrams. FL failure does not occur.

Discussion of the results. Analysis of project tasks at creation MTS (UTS and UTeS) shows that considerable complexity and theoretical research intensity calculations become heavy MTSs, durability and reliability of the elements.

Currently, there is a need of theoretical justification of methods of designing and improving the design calculations of structural elements FL of MTS on the basis of mathematical models of dynamic modes of operation

and to develop recommendations on forecasting possible load for the design of components and systems in general, Bringing them to the level of engineering applications.

CONCLUSIONS. Using this computer program describing the dynamics of the MTS with FL eliminates the physical modeling to study processes associated with conducting field tests on the high seas, which gives substantial savings of financial and material resources, human resources.

Scientific novelty this approach is to improve the FL design methods based on mathematical models FL of MTS (with the development of complex computer models: application of new methods of mathematical description), as a theoretical basis for the development of high-performance MTS with FL.

Fig. 8. Antenna mine: 1 – displacer; 2 – top antenna; 3 – mine; 4 – bottom antenna; 5 – anchor

FILUM

2	длина СН, м	1	длина ПА, м
2	ширина СН, м	0.4	ширина ПА, м
1	осадка СН, м	0.4	осадка ПА, м
1000	водоизмещение СН, кг	150	водоизмещение ПА, кг
3	Плавучесть СН	-0.1	Плавучесть ПА
2.6	коэф. сопр. СН	2	коэф. сопр. ПА
0	стат. время СН, с	1000	стат. время ПА, с
Возможность вертикал. перемещ. в стат. время (1-да, 0-нет)			
0	СН	0	ПА
20	количество элементов ГС	0	ампл. верт. кол. СН, м
0.3	число Куранта	0	част. верт. кол. СН, Гц
250	время моделирования, с		
100	длина ГС, м	0	Нач. коорд. ПА по X, м
14	диаметр ГС, мм	0	Нач. коорд. ПА по Y, м
0.15386	масса ГС, кг/м	80	Нач. коорд. ПА по Z, м
9.55e8	модуль Юнга ГС, Па	-60	Нач. коорд. СН по X, м
2e4	сила разрыва ГС, Н	0	Нач. коорд. СН по Y, м
0.025	тангенц. коэф. сопрот. ГС	0	Нач. коорд. СН по Z, м
1.8	норм коэф. сопрот. ГС	1	Vx, м/с
0.5	коэф. трения ГС о преграду	1	Vy, м/с
		0	Vz, м/с
1000	плотность воды, кг/м3	0	Gx_ПА, Н
10	скорость ветра, м/с	0	Gy_ПА, Н
0	направление ветра, град	0	Gz_ПА, Н
80	средняя глуб. моря, м	50	Водоизмещение поплавка, кг
-30	ампл. изм. глуб. моря, м	-0.5	Плавучесть поплавка
10	коорд. изм. глуб. моря, м	50	Расст. от коренного конца ГС до поплава

Fig. 9. Fragment working dynamics simulation program window dynamics floating buoy after data input for the case 3

List of literature:

- [1] Трунин К.С. Уравнения динамики элемента гибкой связи морской привязной системы. *Збірник наукових праць НУК*. 2017. № 1(468). С. 18–25 [in Russian].
- [2] Трунин К.С. Математическая модель двух связанных элементов гибкой связи морской привязной системы. *Збірник наукових праць НУК*. 2017. № 2(469). С. 3–10 [in Russian].
- [3] Трунин К.С. Динамика морской привязной системы с гибкой связью *Збірник наукових праць НУК*. 2017. № 3(470). С. 3–10 [in Russian].

- [4] Трунин К.С. Алгоритм моделирования динамики морской привязной системы с гибкой связью. *Підводна техніка і технологія* : Матеріали всеукраїнської науково-технічної конференції з міжнародною участю: в 2 ч. Ч. 1. Миколаїв : НУК, 2014. С. 36–42 [in Russian].
- [5] Трунин К.С. Компьютерная модель динамики морской привязной системы с гибкой связью. *Збірник наукових праць НУК*. 2017. № 4 (471). С. 3–13 [in Russian].
- [6] Берто Г. Океанографические буи. Ленинград : Судостроение, 1979. [in Russian].
- [7] Греку Р.Х., Острцов Г.А., Пучкин В.А., Черкасова А.В. (1978). Дрейфующие буи для исследования течений в океане. Севастополь : МГИ. Препринт. 1978. № 2. 18 с. [in Russian].
- [8] Иконников И.Б., Гаврилов В.М., Пузырев Г.В. Подводные буксируемые системы и буи нейтральной плавучести. Санкт-Петербург : Судостроение, 1993 [in Russian].
- [9] Тарасюк Ю.Ф. Международные океанографические экспедиции. *Человек, море, техника : сборник*. Ленинград : Судостроение, 1980. С. 30–40 [in Russian].
- [10] Жмур В.И. Зачем вода течёт в воде? *Популярная механика*. 2013. № 7 (129). С. 38–42 [in Russian].
- [11] Гайский В.А., Артёмов Ю.Г., Блинков В.А. Автоматизированные системы с буксируемыми приборами в океанологических исследованиях. Киев : Наук. Думка, 1987 [in Russian].
- [12] Калюх Ю.И., Горбань В.А. (1986). Квазистатистический анализ притопленных буйковых океанографических систем. Вып. 53. Киев: Ин-т гидромеханики УССР, 1986. С. 72–76 [in Russian].
- [13] Кенни Дж. Е. Техника освоения морских глубин. Вып. 38. Пер. с англ. Ленинград : Судостроение, 1977 [in Russian].
- [14] Королёв В.И. Трёхмерная задача о движении системы тел в потоке. *Гидродинамика*, Вып. 38. Киев : Наукова думка, 1978. С. 59–76 [in Russian].
- [15] Королёв В.И., Лемешко Ё.А. (1978). Равновесие системы гибкая нить – тело в трёхмерном потоке жидкости. *Гидромеханика*, Вып. 38. Киев : Наукова думка, 1978. С. 108–112 [in Russian].
- [16] Кувшинов Г.Е., Наумов Л.А., Чупина К.В. Системы управления глубиной погружения буксируемых объектов. Монография. Владивосток : Дальнаука, 2005 [in Russian].
- [17] Кульмач П.П. Якорные системы удержания плавучих объектов (Вопросы статики и динамики плавучих сооружений на якорях). Ленинград : Судостроение, 1980 [in Russian].
- [18] Виноградов Н.И., Гутман М.Л., Лев И.Г., Нисневич М.З. Привязные подводные системы. Прикладные задачи статики и динамики. Санкт-Петербург : Изд-во С.-Петерб. ун-та, 2000 [in Russian].
- [19] Принципы построения технических средств исследования океана / Отв. ред. д.т.н. В.С. Ястребов. Москва : Наука, 1982.
- [20] Самоходные необитаемые подводные аппараты / Ред. И.Б. Иконников. Ленинград : Судостроение, 1986 [in Russian].
- [21] Шехватов Б.В. Океанографические буи и буйковые лаборатории. *Проблемы исследования и освоения Мирового океана* / Ред. А.И. Вознесенский. Ленинград : Судостроение, 1979. С. 183–204 [in Russian].
- [22] Ястребов В.С. Методы и технические средства океанологии. Ленинград : Гидрометеоздат, 1986 [in Russian].
- [23] Агеев М.Д., Касаткин Б.А., Киселёв Л.В. Автоматические подводные аппараты. Ленинград : Судостроение, 1981 [in Russian].
- [24] Бугаенко Б.А., Галь А.Ф. (2012). Качка на нерегулярном волнении плавучих объектов, закреплённых на предварительно натянутых гибких связях. *Збірник наукових праць НУК ім. адм. Макарова*. 2012. № 1. С. 38–42 [in Russian].
- [25] Дмитриев А.Н. Проектирование подводных аппаратов. Ленинград : Судостроение, 1978 [in Russian].
- [26] Лаврентьев М.А., Шабот Б.В. Проблемы гидродинамики и их математические модели. Москва : Наука, 1977 [in Russian].
- [27] Лобанов В.А. Справочник по технике освоения шельфа. Ленинград : Судостроение, 1983 [in Russian].