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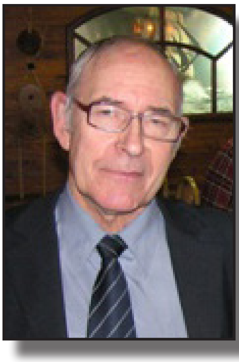
Drilling Vessels: Movement, Displacement and Holding



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ABSTRACT

The monograph considers the features of the dynamics of drilling vessels designed to work in the sea. The complex of theoretical studies included in the monograph is aimed at solving problems related to substantiation of features of dynamic positioning system of a drilling vessel, necessary for its operation in the open sea conditions.

The conditions for operation of the automatic position-keeping system of a vessel are determined by the wind and wave roughness and the allowable flow speed.

The proposed algorithms for solving problems of control of a drilling vessel represent a digital-analog complex, that is due to non-linearity of tasks being solved and the presence of logical conditions in the algorithms.

The control model developed by the authors provides the possibility of its technical implementation.

Keywords: *sea transport, oil production, mathematical model, drilling vessel, positioning, spatial movement, control system.*

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For the original Russian text of the review please see p. 296.

Publishing houses «Vuzovskiy uchebnik» and «Infra-M» jointly published in the form of a monograph the book of V. A. Kramar, V. R. Dushko and V. V. Dushko entitled «Generalized mathematical model of spatial movement of a drilling vessel». As the authors note, the monograph discusses the method of constructing a generalized mathematical model of spatial movement of a drilling vessel, taking into account the mutual influence of various types of movement, as well as changes in the parameters of the vessel depending on the type of work performed.

The book is intended for students, master's students and Ph.D. students of mechanical engineering and instrument-making universities, as well as students of the departments of retraining and advanced training in the field of control systems, oceanography and shipbuilding. The content of the monograph will undoubtedly arouse interest among a wide range of specialists interested in the problems of development of the World Ocean and the continental shelf, following rapid development of mining technologies in marine environment.

Drilling vessels occupy one of the central places in the general spectrum of technical means for studying and developing the World Ocean and the continental shelf. They are designed to work in conditions of sea swell, wind and sea currents, conduct exploratory drilling at different depths in large areas of sea areas. These vessels are highly complex, using a variety of marine technologies, they perform work referring to installation of underwater equipment, tripping, drilling, working with outboard instrumentation, being equipped with a complex of technological equipment for well construction with vessel positioning systems over the wellhead.

Algorithms for generating control actions in the positioning system of a drilling vessel should ensure not only optimization of the vessel positioning process, but also predict the likelihood of emergencies and its minimization. Therefore, there are special requirements for the accuracy of measuring the coordinates of the vessel, the characteristics of waves, wind speed and current and other parameters. For measurements, systems operating with different physical principles can be used, there are hydroacoustic systems, satellite navigation systems, radio communication with coastal beacons, inclinometric and gyro-inertial systems.

The listed features of drilling vessels require the solution of various theoretical problems, carrying out of experimental studies, development of requirements for the created equipment, ensuring the effective operation of the vessel.

The studies cited in the monograph under review are aimed at solving these problems and continue the work begun in a number of publications by other authors. The monograph contains seven chapters, conclusion and bibliography. It covers a range of issues related to the theory, design, operation of drilling vessels, the solution of which is aimed at justifying and creating a system for automatic keeping the vessel above the point of drilling (dynamic positioning system). As the main problems that are essential for development of the system of automatic keeping of the vessel, the authors point out the following:

- development of mathematical models of drilling vessels, which take into account the specifics of design of vessels, drilling equipment and technology of drilling operations;
- obtaining calculated ratios to determine the strength of the retaining (stop) by active controls;
- development of principles for constructing a system for measuring displacement of a drilling vessel and ensuring the required accuracy of these measurements;
- development of the structure of the automatic position-keeping system of a drilling vessel.

Taking into account the fact that during the operation of a drilling vessel, not only external forces acting on vessels (wave pressure, wind, current, propulsive forces and active thrusters) but also the dynamic characteristics of the vessel-drilling equipment system change, the authors divide the dynamics of a drilling vessel into separate periods:

- initial period: from the moment the vessel is kept above the point of drilling to the beginning of movement of masses of drilling equipment;
- preparatory period in which the drill string is lowered, which is characterized by a change in the hydrodynamic characteristics of the vessel and the moments of inertia of the system;
- drilling period during which the vertical forces acting on the drill string change;
- end period (the period of pipes lifting).

To describe the dynamic characteristics of the vessel–drilling equipment system, several coordinate systems are introduced in the work: a system that is stationary in space and three coordinate systems associated with the vessel, then the relationships between these systems are described through Euler angles.

The basic part of the work is a chapter called «General relations», which is devoted to development of equations of motion of a drilling vessel. To obtain them, known methods of theoretical mechanics and fluid mechanics are used. However, derivation of these equations has specific features. So, to describe movement of masses of drilling equipment vertically, in addition to the vector of external forces and the main moment of external forces, the authors introduce the concept of the vector of the momentum of particles thrown from the surface of the body per unit of time, and the vector of the moment of the momentum of the particles thrown per unit of time, differentiating the mass of pipes being moved in time. This accounting of changes in masses of pipes being moved extends both to the moments of inertia of the masses and to the attached masses of the fluid, the magnitude of which depends on the length of the drill string.

The equations of the dynamics of the drilling vessel (by definition of the authors – the generalized equations of the dynamics of the drilling vessel), are obtained for the case of movement of the vessel on regular waves. For these purposes, the technique adopted in hydromechanics for deriving such equations was used; in this case, the boundary conditions for equality of the derived potentials from the velocities of the system of waves on the surface and the potential of a perturbed fluid motion (diffracted waves) are introduced into the velocity vector of the origin of coordinates. The equations of motion take into account the wave damping caused by the waves of the vessel during rolling.

The system of equations is supplemented by equations for the components of forced oscillations in the case of vertical and horizontal-transverse movement of the vessel on regular waves.

The generalized equations of motion of a drilling vessel on regular waves allow us to describe the dynamics of the vessel's movement in any of the periods identified by the authors as private models. These issues are considered separately, in particular, a detailed form of the equation of the vessel's motion during the preliminary period (corresponding to the lowering period of the pipe string) is given, while the masses, the moments of inertia and the attached masses of the fluid are assumed to be constant. The simplified formulation also takes into account the current rate, but its effect on the dynamics is not considered. In conclusion, a system of very cumbersome differential equations resolved with respect to derivatives by speeds of motion is given. In these equations, coefficients are expressed in terms of vessel parameters.

As external forces acting on a drilling ship, the authors consider:

- restoring forces: metacentric stability formulas are used;
- damping forces of viscous nature (forces of resistance to movement of the vessel);
- wave pressure forces;
- forces acting on propulsion and thrusters;
- wind pressure forces.

The listed forces are recommended to be determined by expressions borrowed from other sources. The forces and moments of these forces are represented as projections on the axes of the adopted coordinate systems.

Particular attention is paid to the influence of drilling equipment on the parameters of the equation of motion of the vessel. At the same time, a change in the position of the center of mass of the vessel–drill string system is considered. A differential equation has been compiled that allows to determine the position of the center of mass of the vessel at any stage of lowering (lifting) of the drill string.

The problem of changing the attached masses of fluid of a drill string depending on its length is considered. The problem is solved with the assumption that the column of pipes can be schematized with a triaxial ellipsoid. The calculated expressions for all the attached masses of the column are obtained. For the drilling vessel – a column of pipes system, the attached masses are determined by summing the attached masses of the vessel and the column.

The changes of the moments of inertia of masses of vessel—drill string system are considered. Exact solutions for the moments of inertia of a pipe string and approximate expressions for the moments of inertia of the masses of vessel—drill string system are given. According to the results of research on the change in the moments of the attached masses, numerical calculations were performed and the impact of drilling equipment on the parameters of the vessel dynamics equation was estimated. The conclusion is made about the relatively small effect of changes in the attached masses and, as a result, about the possibility of neglecting this change, as well as about the need to study the effect on movement of the drilling vessel of the changes in the center of mass of the vessel—drill string system. In addition to the chapters related to compilation and analysis of the equations of motion, a general brief description of the active controls for keeping the drilling vessel at a given point is given, as well as expressions for determining some characteristics of their work (stop, torque, power consumption) borrowed from other sources.

Based on minimization of the required power, the question of choosing the optimal position of the drilling vessel with respect to the direction of wind and current is also studied. The criteria considered above are used as criteria for optimality.

A separate chapter is devoted to displacement of the drilling vessel. The systems currently used to determine the position of the vessel in the open sea are analyzed: radio navigation (satellite and with landmarks); inertial navigation systems; astronavigation systems; and also the special methods inspired by features of work of the drilling vessel which are dynamometric, inclinometric, hydroacoustic methods.

It is concluded that it is expedient to use sonar systems to determine the position of the floating base.

The task of determining displacement of the drilling vessel relative to the beacon according to the measurement data of the differential-distance-measuring system is considered.

The systems of equations describing the relationship of coordinates of the beacon and receivers are compiled and analyzed. It is noted that the direct method for solving these equations does not solve the problem of determining the coordinates of the vessel due to irrationality of the system. The conditions that must be met by the coordinates of the receivers to obtain a solution to the problem and ensure necessary accuracy are given. An algorithm has been developed for calculating the coordinates of a beacon (or receiver offset relative to a beacon). The problem of determining the horizontal displacements of a drilling vessel during rolling is considered, the necessary relations are obtained. This solves the problem of the influence of the angles of swing on the measurement errors. The calculations of the errors of measurements of the coordinates of the vessel depending on the pitching angles are given.

The last chapter of the monograph is aimed at developing a system for automatic position-keeping of a drilling vessel. When setting the task, the authors proceed from the fact that keeping of a drilling vessel is possible when installing two or more automated control systems, each of which can execute two control actions determining stop force and turning angle (other automatic control systems are not considered). As a result, when a vessel is subjected to currents, winds and waves, with the general requirement of ensuring high accuracy, it is necessary to ensure automatic control of the automated control system, that is, development of an automatic control system is required.

The task of the automatic control system of the ACS is formulated by the authors as follows:

1. The control system of ACS must ensure stabilization of horizontal displacements of the vessel with the required accuracy.

2. The system should provide control over the course angle so that its current value coincides with the optimal value that minimizes the power spent for the control.

The authors proposed a block diagram of an automatic control system, which is based on the following principles. The system, due to the presence of unmeasurable disturbances (wave pressure), inaccuracies in the calculation of pressure forces and wind should be built on the combined principle in digital-analog form. The position of the vessel as an object of control is determined by displacements relative to the sonar beacon installed on the seabed. The swell and pitching characteristics of the vessel are considered to be interference. Each of the external disturbing influences (wind, current) is characterized by speed and direction. Stop forces of ACS and their angles are control actions. The sonar system measures the difference at the arrival of signals at the receivers, according to the results of those measurements, the coordinates of the vessel are determined through the computer complex. The deviation control unit generates intermediate control actions. The block for optimizing the stop forces optimizes the intermediate control actions in digital form by the stop force and the control angles used by the automatic drive to track the stop forces and the turning angles. Measured values are wind and current angles and their speeds, vessel horizontal displacements and course heading. Implementation of the proposed control system is possible only by simplifying the model of the drilling vessel.

This simplification of motion control is performed by the authors considering the action of a number of favorable factors: a small deviation of the vessel from the origin of coordinates, limited parameters of pitching (if necessary, by installing dampers, etc.). Based on the results of simplified equations of motion and their linearization, the analysis of optimal controls for random stationary perturbations is performed. As a criterion for optimality of control, a functional is adopted that depends on coordinates and control. To minimize the functional while limiting the coordinates of the vessel with a permissible range of deviations, the method of indeterminate Lagrange multipliers and minimum conditions of the criterion in the form of the Euler-Poisson equations are used. For the perturbations given by the correlation functions, the control laws are obtained, the system parameters are optimized. Using the method of indefinite Lagrange multipliers, the problem of synthesizing system parameters has been solved.

At the end of the work, the equations of motion were simplified on the basis of the assumption that effective pitching pacifiers were installed on the vessel, as a result of which the pitch angles and their derivatives are zero. Additional simplifications of the equations of motion in a fixed coordinate system and their linearization are made on the basis of the condition that the phase coordinates of the vessel differ little from their values in the initial state. Simplified equations of motion of a drilling ship in a fixed coordinate system in deviations from the initial state are given in the work in expanded form. These equations are the basis for the synthesis of a closed system that meets the requirements of accuracy with minimal simplifying effects. The control system must meet the requirements for the maximum permissible deviations for linear coordinates and (for reasons of economy of control) deviations for the yaw angle for the total time of the system.

The solution of the problem is to determine the optimal control actions and the corresponding optimal movements that deliver the minimum of the functional from the vector, the components of which are the measured coordinates of the vessel, the control vectors and the matrix of weights with varying parameters. Finding the minimum of the functional is also performed by the method of indefinite Lagrange multipliers, taking into account the necessary conditions in the form of the Euler equation.

Studies of ACS dynamics of a drilling vessel in a fixed coordinate system were performed, and conclusions were obtained for the system of equations of the dynamics of a linearized object for two projections of the stop and moment forces with different parameters, the choice of which can be used to achieve any accuracy of the system. The authors, on the basis of the studies carried out on the model of the automatic control system, conclude that the proposed control law is appropriate. The calculations were carried out for a drilling vessel with a displacement of D = 7200 tons with some minor simplifications of the control system. The model performed the tasks of choosing the optimal course angle, calculating the control actions, converting the projections of the control forces and moments into the stop forces and the angles of rotation of ACS.

Main conclusions

The monograph discusses the features of the dynamics of drilling vessels designed to work in sea conditions. The complex of theoretical studies included in the monograph is aimed at solving problems related to substantiation of features of the dynamic positioning system of a drilling vessel, necessary for its operation in the conditions of the open sea.

Creating a dynamic positioning system requires solving many complex problems, which is due to a complex of objective reasons:

• the problem of determining the external forces acting on the vessel (wave pressure, wind pressure, sea current, forces on propulsion and thrusters), which are determined in analytical form only approximately;

• irregularity of sea waves, whose characteristics are described by probabilistic methods;

• complexity of the formal description of the dynamic system drilling vessel–drill string;

• technical problems of determining the coordinates of the vessel with required accuracy and its mathematical justification;

• complexity of the integrated accounting of all existing factors and the synthesis of the optimal control system, etc.

In this paper, many of these problems are solved. An analysis of the studies presented in the monograph shows that they are performed at a sufficiently high level. It is noteworthy that the work is characterized by a variety of tasks, their complexity, originality of the approach to the solution, wide use of various methods of the analytical apparatus of mathematics, mechanics and hydromechanics. The results obtained highlight the high quality of the research.

The studies performed by the authors show that to ensure the operation of a drilling vessel under conditions of wave action, wind and sea flow, such a vessel must be equipped with a set of measuring and automatically controlled devices acting on the vessel, ensuring its positioning over the well within the deviations allowed by the design features of the drilling equipment.

The authors have developed proposals for the structure of the system that performs positioning tasks. As the main tasks of controlling of the system of automatic position-keeping of a drilling vessel, the authors single out:

• determination of the optimal angles of the vessel;

• construction of a disturbance scheme in the form of projections of forces and moments in the coordinate system associated with the vessel;

• transformation of projections of forces and moments into optimal values of real controls, in the form of stop forces and angles of rotation of active controls.

The proposed system for functional purpose is divided into two main components:

1. Measuring complex that includes automatic measurement of heading angle and wind and current speed vectors, vessel's heel and trim angles and hydroacoustic meter of arrival time differences for four receivers.

2. Combined system for solving a complex of control tasks, including an optimizer of the vessel's heading angle, a calculator of projections of wind and current forces on the coordinate axes associated with the vessel, a control unit for deviation, an optimizer for transforming the projections of forces on the coordinate axes into stop forces and turning angles of active controls, as well as an automated set of tasks for stop forces and turning angles of active controls.

The conditions for operation of the automatic holding system of a vessel are determined by the wind and wave roughness and the allowable flow speed. The developed control block diagram provides the possibility of its technical implementation.

The proposed algorithms for solving control problems form a digital-analog complex, that is due to the non-linearity of the tasks being solved and the presence of logical conditions in the algorithms. In this complex, the digital part provides development of control laws for deviation, solution of optimization problems, calculation of vessel displacement based on data and the measuring system. The analog part measures the physical quantities necessary for control and coordination of the control objects with the digital part.

For the reasons listed above, many of the problems considered in the monograph were solved with introduction of substantial simplifications. The assessment of reliability of the obtained solutions can be given only by the results of a simulation modeling or full-scale experiment.

Since the studies cited in the monograph are largely exploratory in nature, the authors carried out a number of calculations, the purpose of which is to reveal the role of individual parameters of the vessel–drill string system on the dynamic characteristics of this system. In particular, it shows a relatively weak effect of changes in the inertial characteristics of the system when lowering the drill string, a direct dependence of the errors in determining the coordinates of the vessel on the amplitudes of pitching, etc.

As an informative remark, the following should be noted:

In my opinion, an error was made in formulation and solution of the problem of changing the applicability of the center of gravity of a vessel when lowering (lifting) the column of pipes. As it is known, if there is a suspended load on the vessel, such as a column of pipes, the weight force is applied at the point of suspension and its applicability does not depend on the actual position of this load in height. The value of the center-of-gravity applicability of the vessel–drill string system can change only due to redistribution of masses between the vessel and the drill string. Such a change is simply found from consideration of the static moment of the mass of the vessel and the mass of the drilling equipment.

The bibliographic list for the monograph seems to be insufficient. There is a large list of works published on the issues under consideration that could broaden the stated view of the problems to be solved. ●