UDC 62-523: 62-83-52 (075.8)
DOI https://doi.org/10.32782/3041-2080/2025-5-13

DRILLING RIG DRIVE PARAMETER IDENTIFICATION SYSTEM

Khilov Victor Serhiiovytch,
Doctor of Technical Sciences, Professor,
Professor at the Department of Automation, Electrical and Robotic Systems
LLC "METINVEST POLYTECHNIC "TECHNICAL UNIVERSITY"
ORCID ID: 0000-0002-5583-4323

Dyfort Viktor Vasilyevich,
Student
LLC "METINVEST POLYTECHNIC "TECHNICAL UNIVERSITY"

Pavlyshyn Serhii Volodymyrovych,
Student
LLC "METINVEST POLYTECHNIC "TECHNICAL UNIVERSITY"

Pavlyshyna Olena Yurivna,
Student
LLC "METINVEST POLYTECHNIC "TECHNICAL UNIVERSITY"

The purpose of the research is to develop and synthesize an effective system for identifying the parameters of the drilling rig drive, considering the specifics of its dynamic characteristics, to increase the accuracy of modeling, control and diagnostics of the technical condition of the drive.

Research methodology. In the research process, a systematic approach was used to synthesize a system for identifying the parameters of the drilling rig drive, which involves a phased analysis of the dynamic characteristics of the control object, the development of an adequate mathematical model, and the implementation of adaptive identification algorithms.

Research findings. The following methods of identifying drive parameters were analyzed: the least squares method (LSM), the model method with a reference adaptive mechanism (MRAS), Kalman filters (KF, EKF, UKF), frequency analysis methods, methods based on artificial intelligence (AI). Regarding the selected identification object, it is rational to apply the canonical non-search gradient self-tuning algorithm using an "auxiliary operator", since it is possible to synthesize the desired algorithm based on integration operations with subsequent significant simplification, which contributes to increasing the speed of the entire system.

Originality. The scientific novelty of the research lies in the development and synthesis of a new system for identifying the parameters of the drilling rig drive, which provides increased accuracy and speed using adaptive data processing algorithms and mathematical modeling. Unlike existing approaches, the work first proposes a method for combining real experimental data with an analytical model of the drive to refine dynamic parameters in real time. This allows significantly improving the efficiency of drive control in variable drilling conditions.

The practical value of the research lies in the development of an effective system for identifying the parameters of the drilling rig drive, which allows for the accurate determination of variable dynamic characteristics of the drive in real time. The proposed approach provides increased control accuracy, reduced energy consumption, timely detection of deviations in the operation of the equipment and prediction of its technical condition. This contributes to increasing the reliability of drilling operations, reducing the risk of accidents and reducing equipment downtime, which is extremely important for mining and ore enterprises.

Key words: *electric drive, parameter identification, adaptive control.*

Хілов Віктор, Дифорт Віктор, Павлишин Сергій, Павлишина Олена. Принципи побудови систем привода шарошкових бурових верстатів для кар'єрів Криворіжжя

Мета дослідження полягає у розробці та синтезі ефективної системи ідентифікації параметрів привода бурового верстата з урахуванням специфіки його динамічних характеристик із метою підвищення точності моделювання, керування та діагностики технічного стану привода.

Методика дослідження. У процесі дослідження було використано системний підхід до синтезу системи ідентифікації параметрів привода бурового верстата, що передбачає поетапний аналіз динамічних характеристик об'єкта керування, розробку адекватної математичної моделі та впровадження алгоритмів адаптивної ідентифікації.

Результати дослідження. Проаналізовані методи ідентифікації параметрів привода: метод найменших квадратів (МНК), метод моделі з еталонним адаптивним механізмом (MRAS), калманівські фільтри (KF, EKF, UKF), методи частотного аналізу, методи на основі штучного інтелекту (AI). До вибраного об'єкта ідентифікації раціонально застосувати канонічний непошуковий градієнтний алгоритм самоналаштування з використанням «допоміжного оператора», оскільки при цьому можна синтезувати шуканий алгоритм на основі операцій інтегрування з подальшим істотним спрощенням, що сприяє підвищенню швидкодії всієї системи.

Наукова новизна дослідження полягає у розробці та синтезі нової системи ідентифікації параметрів привода бурового верстата, яка забезпечує підвищену точність і швидкодію завдяки використанню адаптивних алгоритмів обробки даних та математичного моделювання. На відміну від існуючих підходів, у роботі вперше запропоновано методику поєднання реальних експериментальних даних з аналітичною моделлю привода для уточнення динамічних параметрів у режимі реального часу. Це дає змогу суттєво покращити ефективність керування приводом у змінних умовах буріння.

Практична значимість дослідження полягає у розробці ефективної системи ідентифікації параметрів привода бурового верстата, яка надає можливість у реальному часі точно визначати змінні динамічні характеристики привода. Запропонований підхід забезпечує підвищення точності управління, зниження енерговитрат, своєчасне виявлення відхилень у роботі обладнання та прогнозування його технічного стану. Це сприяє підвищенню надійності бурових робіт, зниженню ризиків аварій і скороченню простоїв техніки, що є надзвичайно важливим для підприємств гірничо-рудної галузі.

Ключові слова: *електричний привод, ідентифікація параметрів, адаптивне керування.*

Introduction. The rotation drive of a drilling rig is characterized by changes in the moment of inertia during the assembly and disassembly of the rig, as well as changes in the parameters of the armature circuit – inductance and resistive resistance – during the operation of electromechanical equipment. This leads to changes in transmission coefficients and time constants, which negatively affects the maintenance of optimal parameters in the process of drilling blast holes. Moreover, the refusal to use sensors on the motor requires the use of a state identifier for the control process, the parameters of which must exactly correspond to the control object. Only in this case is it possible to maintain the rock destruction process with a conical bit at an optimal level.

Literature review. The following areas of research are currently undergoing active development: identification of asynchronous motor parameters, taking into account low sensitivity to measurement errors [1]; monitoring and diagnostics of electromechanical systems in drilling equipment, in particular diagnostic systems for mobile drilling rigs [2]; modernization of electric drives for drilling systems using thyristor or frequency converters [3]; automated electric drives for drill rig winches with PLC control and reconfiguration [4].

Classic algorithms and models are studied: in [5], algorithms are proposed for identifying the parameters of a T-like asynchronous motor circuit that is resistant to data errors when the rotor is stationary. This uses the assumption of a reduction in the number of unknown parameters, which simplifies calculations, with proof of minimal impact on processes. In [6], mathematical modeling and regression approaches are developed; in [7] – a model for modernizing the electric drive of a booster unit is developed, where the dependence of the moment of inertia and other parameters is approximated using polynomial regression and Taylor series, including the parameter of air compressibility depending on pressure and temperature; in [8], the results of modeling the dynamic characteristics of an electric drill with a thyristor frequency converter are presented: calculation of the transfer function, control times, oscillatory characteristics, and optimal start/braking modes; in [9] – parameters of the tail system and brake unit with algorithms for state prediction, maintenance, and devices based on controllers and sensors are presented; in [10] – a Bayesian approach is used to estimate the parameters of torsional dynamics in a laboratory model, modeling the uncertainty of values in the form of Gaussian noise.

Research objectives. Thus, a significant contribution has been made to the identification of asynchronous drive parameters, modeling, and modernization of individual drilling rig units. Regarding the selected identification object, it is rational to apply a canonical non-search gradient self-tuning algorithm using an “auxiliary operator,” since this makes it possible to synthesize the desired algorithm based on integration operations with subsequent significant simplification, which contributes to increasing the performance of the entire system.

Main material. The structure of the drive system is known a priori, so identification boils down to finding the values of the transfer coefficients. The task is to synthesize an adaptive observation device that estimates the state vector of the object and identifies its parameters [11].

These parameters can be found using direct calculation identification algorithms or an adaptive model. The use of direct calculation algorithms requires direct or indirect measurement of state vectors, and for this it is necessary to know their values at discrete moments in time. In reality, measurement errors occur, and this imposes significant limitations on the application of direct computational identification algorithms. Therefore, we solve the problem in the field of identification using an adaptive or self-tuning model. At the same time, at each current moment in time, the instantaneous mismatch between the output vector of the model and the vector of the real process is minimized. This requires the use of gradient adjustment methods – search and non-search [12].

Search engines require numerical differentiation, which is achieved by introducing search parameter variations and using synchronous detection. In non-search systems, the “auxiliary operator” principle and sensitivity theory are used to determine the gradient. Therefore, with regard to the object of identification under consideration, it is rational to apply a canonical non-search gradient self-tuning algorithm using an “auxiliary operator,” since it is possible to synthesize the desired algorithm based on integration operations with subsequent significant simplification, which contributes to increasing the performance of the entire system.

By selecting voltage as the input variable and motor armature current as the output variable, we obtain the transfer function of the identification object

$$I(p)=\frac{p/L_A}{p^2+R_Ap/L_A+C_EC_M\Phi_H^2/J/L_A}U(p), \qquad (1)$$

where p is the Laplace operator;

L_A is the inductance of the armature circuit;

R_A is the active resistance of the armature circuit;

C_E, C_M is the structural steel of the DC motor;

Φ_H is the rated magnetic flux of the motor;

$\mathcal{J}$ is the moment of inertia of the drive;

$I(p)$, $U(p)$ are mages of current and voltage.

In the domain of originals, equation (1) will transform to the form

$$\frac{d^2I}{dt^2}+\frac{L_A}{R_A}\frac{dI}{dt}+\frac{C_EC_M\Phi_H^2}{JL_A}=\frac{1}{L_A}\frac{dU}{dt}, \qquad (2)$$

where the moment of inertia, resistive resistance, and inductance of the armature circuit are variable parameters of the control object. If inductance and resistance change slowly over time, then the moment of inertia can change both slowly over time (due to rod wear) and abruptly (during the assembly and disassembly of the drilling rig).

In accordance with the differential equation of the control object (2), we accept a model that is adjustable and described by a second-order differential equation

$$\frac{d^2\hat{I}}{dt^2}+\alpha\frac{d\hat{I}}{dt}+\beta\hat{I}=\gamma\frac{dU}{dt}. \qquad (3)$$

Where the coefficients: α – is directly proportional to the value of resistive resistance, β – is inversely proportional to the moment of inertia, γ – is inversely proportional to inductance, i. e

$$\alpha=R_A/L_A;\quad \beta=C_EC_M\Phi_H^2/L_A/J;\quad \gamma=1/L_A.$$

As a measure of the quality of the self-tuning criterion, we select the objective function, which is determined by the ratio $\varepsilon^2=(I-\hat{I})^2$, i. e., the square of the difference between the actual and restored values of the armature current, which are measured on the identification object and calculated on the model that is built.

One can find the gradients of the model parameter settings:

$$\left.\begin{aligned}\frac{d\alpha}{dt}&=-\frac{1}{T_\alpha}\frac{\partial\varepsilon^2}{\partial\alpha}=\frac{2}{T_\alpha}(I-\hat{I})\frac{\partial\hat{I}}{\partial\alpha};\\ \frac{d\beta}{dt}&=-\frac{1}{T_\beta}\frac{\partial\varepsilon^2}{\partial\beta}=\frac{2}{T_\beta}(I-\hat{I})\frac{\partial\hat{I}}{\partial\beta};\\ \frac{d\gamma}{dt}&=-\frac{1}{T_\gamma}\frac{\partial\varepsilon^2}{\partial\gamma}=\frac{2}{T_\gamma}(I-\hat{I})\frac{\partial\hat{I}}{\partial\gamma}.\end{aligned}\right\} \qquad (4)$$

The sensitivity function of the restored current value with respect to the adjustable parameters α, β, γ, is the function of the parameter’s effect on the restored current value, i. e.

$$\left.\begin{aligned}&\frac{d\gamma}{dt}=-\frac{1}{T_\gamma}\frac{\partial\varepsilon^2}{\partial\gamma}=\frac{2}{T_\gamma}(I-\hat{I})\frac{\partial\hat{I}}{\partial\gamma},\\ &\frac{d^2}{dt^2}\frac{\partial\hat{I}}{\beta}+\alpha\frac{d}{dt}\frac{\partial\hat{I}}{\partial\beta}+\hat{I}+\beta\frac{\partial\hat{I}}{\partial\beta}=0;\\ &\frac{d^2}{dt^2}\frac{\partial\hat{I}}{\partial\gamma}+\alpha\frac{d}{dt}\frac{\partial\hat{I}}{\partial\gamma}+\beta\frac{\partial\hat{I}}{\partial\gamma}=\frac{dU}{dt}.\end{aligned}\right\} \qquad (5)$$

To simplify transformations from the domain of originals, we move to Laplace operator images, from where we explicitly extract the desired sensitivity functions

$$\left.\begin{aligned}\frac{\partial\hat{I}(p)}{\partial\alpha(p)}&=-\frac{p\widehat{I(p)}}{p^2+p\alpha(p)+\beta(p)}=W_{BO}(p)W_{C1}(p);\\ \frac{\partial\widehat{I(p)}}{\partial\beta(p)}&=-\frac{\widehat{I(p)}}{p^2+p\alpha(p)+\beta(p)}=W_{BO}(p)W_{C2}(p);\\ \frac{\partial\widehat{I(p)}}{\partial\gamma(p)}&=\frac{pU(p)}{p^2+p\alpha(p)+\beta(p)}=W_{BO}(p)W_{C3}(p).\end{aligned}\right\} \qquad (6)$$

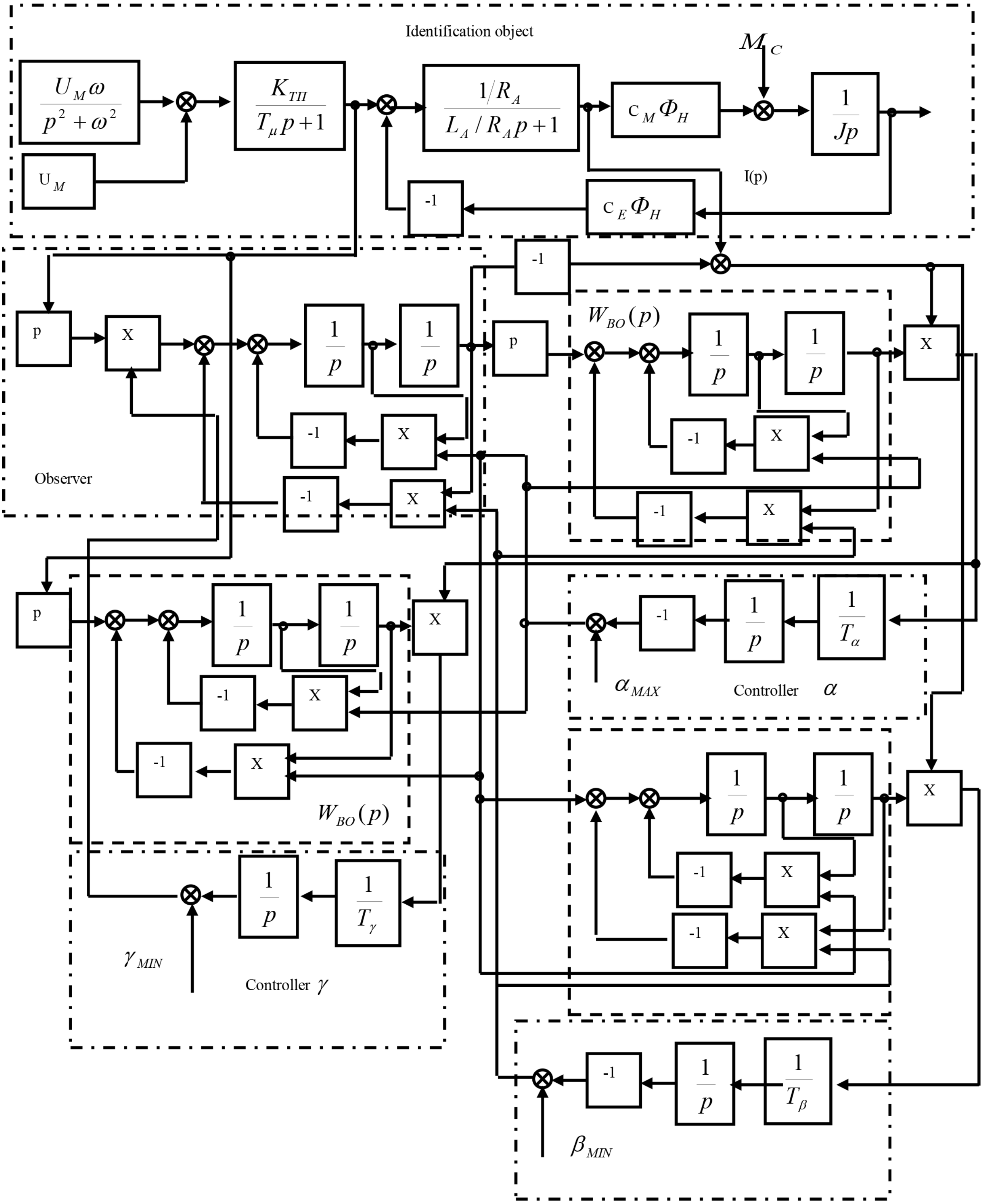

Fig. 1. Structural diagram of the drive parameter identification system of the drilling rig

Since the common part of the auxiliary operator is the same for all configurable parameters and does not contain information specific to each parameter, only essential auxiliary operators are used to simplify the self-tuning circuit and increase its performance.

Thus, the parameter tuning algorithm α, β, γ, where essential auxiliary operators are used, is based on the following system of equations:

$$\left.\begin{aligned} &\alpha(p) = -\frac{2}{T_\alpha p} p\hat{I}(p)(I(p) - \hat{I}(p));\\ &\beta(p) = -\frac{2}{T_\beta \cdot p}\hat{I}(p)(I(p) - \hat{I}(p));\\ &\gamma(p) = \frac{2}{T_\gamma p} pU(p)(I(p) - \hat{I}(p)). \end{aligned}\right\} \qquad (7)$$

The structural diagram of the adaptive drive parameter identification system, which is based on the algorithms of equations (7), is shown in Fig. 1, where the common part of the auxiliary operators is located in dotted rectangles.

Conclusions. During the research, an important scientific and practical task was solved: a method for determining the technical parameters of drilling equipment drives was identified, which allows increasing its efficiency and ensuring the adaptability of the control system to changes in the dynamics of the object.

1. A mathematical model of a drilling rig drive was analyzed, taking into account the main nonlinearities and inertia of the system. This made it possible to create conditions for constructing an adequate structure for the identification mode.

2. The identification system based on an adaptive approach was synthesized, in particular using identification methods based on recursive parameter estimation. This approach ensured high accuracy in determining variable parameters in real time.

3. Simulation modeling was performed, the results of which confirmed the effectiveness of the selected identification system structure. It was established that the system detects parameter changes with minimal time delay and high resistance to interference.

4. Adaptive control of the drilling drive is ensured: thanks to real-time parameter identification, it is possible to dynamically adjust the control system in accordance with changes in load, temperature conditions, component wear, etc.

5. The practical value of the study lies in the fact that the proposed approach can be used in automated drilling equipment control systems to increase equipment life, reduce energy consumption, and prevent emergencies.

6. Further research may be directed toward integrating the developed identification system with intelligent algorithms for predicting the state of the drive and extending the model to multi-channel control.

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Стаття надійшла: 04.08.2025
Стаття прийнята: 28.08.2025
Опублікована: 10.11.2025