УДК 681.518.54

BASIC REGULARITIES OF THE LAW OF THE MOMENT CHARACTERISTICS OF THE ACCOMPANYING INFORMATION SIGNALS OF THE TECHNOLOGICAL PROCESS OF DRILLING

MESHCHERYAKOV L. I. [1]*, *d.t.n., prof.,*
TKACHEV V. S. [2]*, *associate prof.,*
UZELOVSKYI V. O. [3]* *associate prof.,*
ZAIKA L. A. [4]* Senior lecturer.

[1]* Department of computer systems software, State Institution of Higher Eeducation «National Mining University», .Karl Marks ave., 19, 49005, Dnipro, Ukraine, tel. +38-(056)- 747-55-15, e-mail: nmu@nmu.org.ua,

[2]* Department of automation and electrical engineering, State Institution of Higher Education «Prydniprovska State Academy of Civil Engineering and Architecture»,. Chernyshevsky street., 24-A, 49600, Dnipro, Ukraine, tel. +38-(056)- 756-33-80, e-mail: ngg@mail.pgasa.dp.ua, ORCID ID: 0000-0001-6967-6540

[3]* Department of automation and electrical engineering, State Institution of Higher Education «Prydniprovska State Academy of Civil Engineering and Architecture Chernyshevsky street., 24-A, 49600, Dnipro, Ukraine, tel. +38-(056)- 756-33-80, e-mail: ngg@mail.pgasa.dp.ua, ORCID ID: 0000-0001-6967-6540…..

[3]* Department of Foreign Languages, Institution of Higher education «National Mining University», Karl Marks avenue., 19, 49005, Dnipro, Ukraine, tel. +38-(056)- 747-02-05, e-mail: nmu@nmu.org.ua,

Abstract. ***Purpose.*** To reveal the internal nonlinear stochastic connections of technological and technical parameters of drilling complexes through the information characteristics of the accompanying signals of the technological process of drilling, that allows to increase the accuracy of the diagnostics of operational states of drilling complexes to form optimal control influences. ***Methods.*** Methods of moment identification are applied for the study and that stipulates determination of the hidden nonlinear stochastic connections of technological and technical parameters with different operating modes and the state of drilling complexes. ***Results and novelty*** **.**The dependences of the technological parameters of the mechanical speed of the drilling with diamond crowns on the consumption of the flushing fluid, the dependences of the technological parameter of the speed of drilling with diamond crowns on the rotation speed of the drill bits and diamond tools, the dependences of the technological parameter of the mechanical speed of drilling with diamond crowns on the parameters of the loading on the drill bits and diamond tools, dependences of the technical parameter of driving on the diamond crowns on the consumption of the flushing fluid, dependences of the technical parameter of driving on the diamond crown on the ring rotation speed of the drill bits and diamond tools. ***Practical Value.*** Determination and analysis of the specified conditional-moment characteristics of technological and technical parameters of the process of drilling with diamond crowns allows us to set a number of information regularities and that reveals internal linear and nonlinear connections between the basic parameters in different operating modes of drilling complexes. This expands and deepens the information provision of the automated control systems for the technological processes of drilling complexes and leads to an increase in the accuracy and reliability of the definition of the operational technological and technical states of the latter and thus improves the efficiency of the automation of the process of control of driving the boreholes accordingly.

Keywords**:** identification; signals; technological process of drilling; diagnostics; technological and technical parameters; operating states; drilling complexes

ОСНОВНІ ЗАКОНОМІРНОСТІ МОМЕНТНИХ ХАРАКТЕРИСТИК СУПУТНІХ ІНФОРМАЦІЙНИХ СИГНАЛІВ ТЕХНОЛОГІЧНОГО ПРОЦЕСУ БУРІННЯ

МЕЩЕРЯКОВ Л. І. [1]*, *д.т.н., проф.,*
ТКАЧОВ В. С. [2]*, *к.т.н., доц.,*
УЖЕЛОВСЬКИЙ В. О. [3]* *к.т.н., доц.,*
ЗАЇКА Л. А. [4]*ст. викладач.

[1]* Кафедра програмного забезпечення комп’ютерних систем, Державний вищий навчальний заклад «Національний гірничий університет», просп. Карла Маркса, 19, 49005, м. Дніпро, Україна, тел. +38-(056)- 747-55-15, e-mail: nmu@nmu.org.ua,

[2]* Кафедра автоматики та електротехніки, Державний вищий навчальний заклад «Придніпровська державна академія будівництва та архітектури», вул. Чернишевського, 24-А, 49600, м. Дніпро, Україна, тел. +38-(056)- 756-33-80, e-mail: ngg@mail.pgasa.dp.ua, ORCID ID: 0000-0001-6967-6540

[3]* Кафедра автоматики та електротехніки, Державний вищий навчальний заклад «Придніпровська державна академія будівництва та архітектури», вул. Чернишевського, 24-А, 49600, м. Дніпро, Україна, тел. +38-(056)- 756-33-80, e-mail: ngg@mail.pgasa.dp.ua, ORCID ID: 0000-0001-6967-6540
[4]* Кафедра іноземних мов, Державний вищий навчальний заклад «Національний гірничий університет», просп. Карла Маркса, 19, 49005, м. Дніпро, Україна, тел. +38-(056)- 747-02-05, e-mail: nmu@nmu.org.ua.

Анотація. ***Мета.*** Розкрити внутрішні нелінійні стохастичні зв'язки технологічних та технічних параметрів бурових комплексів через інформаційні характеристики супутних сигналах технологічного процесу буріння, що дозволяє підвищити точність діагностування оперативних станів бурових комплексів для формування оптимальних керуючих впливів. ***Методика.*** Для дослідження застосовано методи моментної ідентифікації, що обумовлює визначення прихованих нелінійних стохастичних зв'язків технологічних та технічних параметрів з різними режимами роботи та станом бурових комплексів. ***Результати та новизна.*** Виявлено залежності технологічного параметра механічної швидкості буріння алмазними коронками від витрат промивальної рідини, залежності технологічного параметра швидкості буріння алмазними коронками від швидкості обертання породоруйнівного інструменту, залежності технологічного параметра механічної швидкості буріння алмазними коронками від параметрів навантаження на породоруйнівний інструмент, залежності технічного параметра проходки на алмазну коронку від витрат промивальної рідини, залежності технічного параметра проходки на алмазну коронку від окружної швидкості обертання породоруйнівного інструменту. ***Практична значимість.*** Визначення та аналіз вказаних умовно-моментних характеристик технологічних та технічних параметрів процесу буріння алмазними коронками дозволяє встановити цілий ряд глибинних інформаційних закономірностей, що відкривають внутрішні лінійні та нелінійні зв'язки між основними параметрами в різних робочих режимах бурових комплексів. Це розширює та поглиблює інформаційне забезпечення автоматизованих систем керування технологічних процесів бурових комплексів і веде до підвищення точності та достовірності визначення оперативних технологічних та технічних станів останніх і відповідно підвищує ефективність автоматизації процесу керування проходки свердловин.

Ключові слова: ідентифікація; сигнали; технологічний процес буріння; діагностування; технологічні та технічні параметри; оперативні стани; бурові комплекси

ОСНОВНЫЕ ЗАКОНОМЕРНОСТИ МОМЕНТНЫХ ХАРАКТЕРИСТИК СОПУТСТВУЮЩИХ ИНФОРМАЦИОННЫХ СИГНАЛОВ ТЕХНОЛОГИЧЕСКОГО ПРОЦЕССА БУРЕНИЯ

МЕЩЕРЯКОВ Л. И. [1]*, *д.т.н., проф.*
ТКАЧЕВ В. С. [2]*, *к.т.н., доц.*
УЖЕЛОВСКИЙ В. А. [3]* *к.т.н., доц.*
ЗАИКА Л. А. [4]*ст. преподаватель

[1]* Кафедра программного обеспечения компьютерных систем, Государственное высшее учебное заведение «Национальный горный университет», просп. Карла Маркса, 19, 49005, г. Днепр, Украина, тел. +38-(056)- 747-55-15, e-mail: nmu@nmu.org.ua,
[2]* Кафедра автоматики и электротехники, Государственное высшее учебное заведение «Приднепровская государственная академия строительства и архитектуры», ул. Чернишевского, 24-А, 49600, г. Днепр, Украина, тел. +38-(056)- 756-33-80, e-mail: ngg@mail.pgasa.dp.ua, ORCID ID: 0000-0001-6967-6540
[3]* Кафедра автоматики и электротехники, Государственное высшее учебное заведение «Приднепровская государственная академия строительства и архитектуры», ул. Чернишевского, 24-А, 49600, г. Днепр, Украина, тел. +38-(056)- 756-33-80, e-mail: ngg@mail.pgasa.dp.ua, ORCID ID: 0000-0001-6967-6540
[4]* Кафедра иностранных языков, Государственное высшее учебное заведение «Национальный горный университет», просп. Карла Маркса, 19, 49005, г. Днепр, Украина, тел. +38-(056)- 747-02-05, e-mail: nmu@nmu.org.ua.

Аннотация. ***Цель.*** Раскрыть внутренние нелинейные стохастические связи технологических и технических параметров буровых комплексов через информационные характеристики сопутствующих сигналов технологического процесса бурения, что позволяет повысить точность диагностики оперативных состояний буровых комплексов для формирование оптимальных управляющих воздействий. ***Методика.*** Для исследования применены методы моментной идентификации, что обусловливает определение скрытых нелинейных стохастических связей технологических и технических параметров с разными режимами работы и состоянием буровых комплексов. ***Результаты и новизна.*** Выявлены зависимости технологического параметра механической скорости бурения алмазными коронками от расходов промывочной жидкости, зависимости технологического параметра скорости бурения алмазными коронками от скорости вращения породоразрушающего инструмента, зависимости технологического параметра механической скорости бурения алмазными коронками от параметров нагрузки на породоразрушающий инструмент, зависимости технического параметра проходки на алмазную коронку от расходов промывочной жидкости, зависимости технического параметра проходки на алмазную коронку от окружной скорости вращения породоразрушающего инструмента. ***Практическая значимость.*** Определение и анализ указанных условно-моментных характеристик технологических и технических параметров процесса бурения алмазными коронками позволяет установить информационные закономерности, что открывает внутренние линейные и нелинейные связи между основными параметрами в разных рабочих режимах буровых комплексов. Это расширяет и углубляет информационное обеспечение автоматизированных систем управления технологических процессов буровых комплексов и ведет к повышению точности и достоверности определения оперативных технологических и технических состояний последних и соответственно повышает эффективность автоматизации процесса управления проходки скважин.

Ключевые слова: идентификация; сигналы; технологический процесс бурения; диагностика; технологические и технические параметры; оперативные состояния; буровые комплексы

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Introduction

One of the effective methods of constructing real models of complex automation objects is their identification.In this case, the construction of information models by identification methods is aimed primarily at the development of methods for the operational receiving of the models of control objects. The main feature of using the identification methods exactly to nonlinear objects consists in the fact that they are based on dispersion and other moment characteristics of the random functions of signals, which are measured by sensors installed on the mining electromechanical complexes (MEMC) as essentially complex nonlinear automation objects.

This approach has many positive benefits by facilitating in-depth analysis and sequential or parallel-sequential combination of algorithms for processing stochastic implementations of the initial information, and that allows to interpret the obtained results from general positions and to plan new experiments to specify the models, allowing the opportunity to use the same type of the computing means. Real nonlinear objects like MEMC are usually complex diagnostic and control processes, and of course, their identification.requires the development and use of special methods and techniques.

Purpose

The purpose is to reveal the internal nonlinear stochastic connections of the main technological and technical parameters of drilling complexes [1] by analyzing the moment characteristics of the accompanying signals of the technological process of drilling, which allows to improve the accuracy of the diagnostics of the operational states of drilling complexes (DC) in operating modes of driving boreholes and to expand the possibilities of automated control systems (ACS) in formation of optimal control effects due to increased observation and controllability of MEMC.

Methodology

Methods of moment identification [1] are used for the research, and that stipulates the definition of hidden nonlinear stochastic connections of technological and technical parameters with different operating modes and the state of drilling complexes [2,3].

The technological processes (TP) and MEMC can be defined for an adequate description in the most realistic way in the form of multidimensional models, when the variables considered are vectors corresponding toa a given dimension. To identify this type of models in the«input-output» structure it is necessary to determine the forms of connection and estimate the tightness of the connection between each variable from the vector of output variables $Y_1, Y_2, ..., Y_m$ and each variable from the vector of input variables $U_1, U_2, ..., U_n$.Accordingly, when constructing multidimensional models in the «input-state-output» structure, it is necessary to determine the form of connection and estimate the tightness of this connection between each variable from the vector of output variables $Y_1, Y_2, ..., Y_m$, each variable from the vector of state variables $X_1, X_2, ..., X_p$ and each variable from the vector of input variables $U_1, U_2, ..., U_n$. Undoubtedly, all variables are extremely difficult to use, therefore, on the basis of the determined a priori information, it is practically possible to consider only some specifically limited set for each set of variables, although this reduces the degree of adequacy of the synthesized model.. And here it is important to choose for consideration and use the most informative variables for each set of variablesю.

In this case a reliable informative estimation for the ACS TP tasks, the numerical characteristic of the multiple conditional mathematical expectation or its multiple regression should be used. As it is known, the numerical characteristic of the conditional mathematical expectation of the output $M(\overline{Y} \mid \overline{U})$ as to the input vector $\overline{U}$ is the main characteristic of the form of connection and the general characteristic of the vectors $(Y_1, ..., Y_m, U_1, ..., U_n)$ and is their $(n+m)$-dimensional probability tightness $f_{n+m}(y_1, ... y_m, u_1, ..., u_n)$ as a probabilistic model, and the basic characteristic of TP and MEMC is the conditional probability tightness of the form

$$f_{n+m}(y_1, ..., y_m \mid u_1, ..., u_n) = \frac{f_{n+m}(y_1, ..., y_m, u_1, ..., u_n)}{f_n(u_1, ..., u_n)}$$

Characteristics of the conditional mathematical expectations of each output from each value on each input $M_q(Y_q \mid u_{i,j})$ (*i* – input index, *q* – output index, *j* –index of multiple values) in multiple variant will be written as

$$M_q(Y_q \mid u_{i,j}) = \int_{-\infty}^{\infty} y_q f(y_q \mid u_{i,j}) dy_q .$$

Mathematical expectations of the conditional mathematical expectations $M_q(Y_q \mid u_{i,j})$ as to the coincident values *j* of the input vectors will be determined in the form

$$M_q(Y_q \mid u_{1,j},...,u_{n,j})] = \int_{-\infty}^{\infty} y_q f(y_q \mid u_{1.j},...,u_{n,j})dy_q . \quad (1)$$

Methods of moment identification, like any other body of mathematics, remain meaningful and correct only when certain determined initial conditions are performed. The best conditions which provide the theoretical justification for using these methods are the independence of random variables in a given dimension on the previous and subsequent ones, the normal separation of the output variable with a fixed value of the input variable or the state variable, and the constancy of the conditional variance of the dependent variable of output on the changes in the input or state values. The qualitative decision of the tasks of control is stipulated by the last position. In this case, it is necessary to determine the degree of heteroscedasticity of the objects of control. The effect of heteroscedasticity may arise from many factors: the wear of the equipment (drill bits and diamond tools, armor, lifters, etc.), errors and obstacles in signal measurements, changes in composition of the crashed rock, and a number of other perturbations. The objects of control can appear as heteroscedastic ones in the linearization of the nonlinear objects as well, in this case when the nonlinear object is represented by a linear stochastic one, where the first two moment conditional and unconditional characteristics coincide with the corresponding moment characteristics of the nonlinear objects [1]. Undoubtedly, the study of such objects is complicated in comparison with the study of the linear systems, but in many cases, it is payed off by increasing the accuracy of the study of a linear or nonlinear object.

Results and novelty

The study of certain determined regression models of technological and technical parameters of the drilling process on heteroscedasticity revealed important information characteristics. Thus, heteroscedasticity nonlinear regression model of conditional mathematical expectation $M(V \mid Q)$ (Fig. 1, a) of the dependence of the technological parameter of the mechanical speed of a diamond crown drilling V on the consumption of the flushing fluid Q has a characteristic of a significant decrease in the variable of conditional variance $\pm D(V \mid Q)$ in the zone of rational operating modes (230 – 250 l/min) and an increase at the end of the operating zone (100 та 300 l/min). According to the conditional asymmetries $\pm A(V \mid Q)$ (Fig. 1, b), conditional excesses $\pm E(V \mid Q)$ (Fig. 1, c) and conditional variations $\pm Vr(V \mid Q)$ (Fig1, d) depending on these parameters the increasing linear homoscedasticity of the characteristics in the operating zone at a minimum $M(V \mid Q)$ (250 – 300 l/min) is revealed [4, 5, 6].

It is also typical to minimize the dispersion of conditional asymmetrics $\pm A(V \mid Q)$ and conditional excesses $\pm E(V \mid Q)$ relatively to conditional mathematical expectations $M(V \mid Q)$ in the zone of rational operating modes 220 – 240 l/min (Fig. 1, b, c) and an increase of dispersal with a decrease in consumption of the flushing fluid Q to a value of 100 l/min. The determined dependence of the conditional variation $\pm Vr(V \mid Q)$ in the zone of rational modes is, on the contrary, increasing (Fig. 1,d).

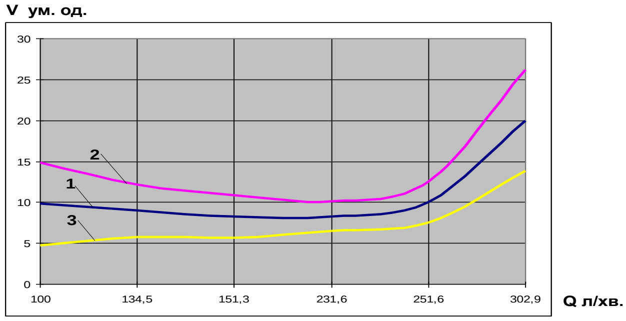
Heteroscestic nonlinear regression model of the conditional mathematical expectation $M(V \mid \omega)$ (Fig. 2, a) of the dependence of the technological parameter of the mechanical speed of drilling with diamond crowns V on the ring rotation speed ω of the drill bits and diamond tools (DBDT) is in line with $M(V \mid Q)$ characteristics on the variables of conditional variances $\pm D(V \mid \omega)$ (Fig. 2, a), conditional asymmetries $\pm A(V \mid \omega)$ (Fig2, b), conditional excesses $\pm E(V \mid \omega)$ (Fig. 2, c) and conditional variations $\pm Vr(V \mid \omega)$ (Fig. 2, d). The difference is characteristic maximization of the conditional excess $\pm E(V \mid \omega)$ in the rational operating zone 220 – 240 l/min. (Fig. 2, c) ana an increase of conditional variations $\pm Vr(V \mid \omega)$ with a decrease of the ring rotation speed ω BDBT to 100 m/s (Fig. 2, d).

The main characteristic of hetero-skew nonlinear regression models of conditional mathematical expectations $M(V \mid H)$ of the dependence of the technological parameters of the mechanical speed of drilling with diamond crowns V on the loading parameters H on DBDT with conditional variances $\pm D(V \mid H)$, conditional asymmetries $\pm A(V \mid H)$, conditional excesses $\pm E(V \mid H)$ and conditional variations $\pm Vr(V \mid H)$ are represented in Fig. 3. The general tendency here is a significant decrease in the dispersal of the estimates of conditional variance $\pm D(V \mid H)$, conditional asymmetry $\pm A(V \mid H)$, conditional excess $\pm E(V \mid H)$ and conditional variation $\pm Vr(V \mid H)$ with the increasing loading H on DBDT . In the zone of rational loading H on DBDT with a maximum $M(V \mid H)$ (1050 – 1150 kGs) these estimates are of constant value. And in the zone to the maximum value of the.mechanical speed of drilling V , the conditional variance $\pm D(V \mid H)$, the conditional asymmetry $\pm A(V \mid H)$ and conditional variation $\pm Vr(V \mid H)$ have homoscedastic characteristics. In contrast to them, the conditional excess $\pm E(V\,|\,H)$ has an icon-variable value in this zone (Fig. 3, c).

Hetero-skew nonlinear regression models of conditional mathematical expectations $M(X\,|\,Q)$ of the dependence of the technical parameter of the driving on the diamond crown X on the consumption of the flushing fluid Q (1) with the conditional variances $\pm D(X\,|\,Q)$, conditional asymmetries $\pm A(X\,|\,Q)$, conditional excesses $\pm E(X\,|\,Q)$ and conditional variations $\pm Vr(X\,|\,Q)$ are shown in Fig. 4. The maximum value of the parameter of driving on the diamond crown X is accompanied by maximum conditional variances $\pm D(X\,|\,Q)$ (Fig. 4, a). Its decrease is observed at the ends of the zone of operating modes on the consumption of the flushing fluid Q.

The characteristic here is significant. The characteristic of the conditional asymmetry $\pm A(X\,|\,Q)$ (Fig. 4, b), is of an informative interest, which has a hetero-skew form with minimization of its own values of deviations from the conditional mathematical expectations $M(X\,|\,Q)$ in the zone of rational operating modes by a typical decrease at the ends of the zone of operating modes on the consumption of the flushing fluid Q. The dependence of the conditional excess $\pm E(X\,|\,Q)$ is due to a decrease in the deviation in the zone of an increase of conditional mathematical expectations $M(X\,|\,Q)$ to extremum and transition to the homoscedastic mode with a decrease $M(X\,|\,Q)$ in the operating zone by the extremum. The dependence of the conditional variation $\pm Vr(X\,|\,Q)$ is represented by a typical decrease of deviations from the conditional mathematical expectations $M(X\,|\,Q)$ at the ends of the operating zones and maximization of the deviation in the range of rational operating modes.

Hetero-skew nonlinear regression models of conditional mathematical expectations $M(X\,|\,\omega)$ ofr the dependence of the technical parameter of driving on a diamond crown X on the ring rotation speed ω of DBDT with conditional variances $\pm D(X\,|\,\omega)$, with conditional asymmetries $\pm A(X\,|\,\omega)$, conditional excesses $\pm E(X\,|\,\omega)$ and conditional variations $\pm Vr(X\,|\,\omega)$ are represented in Fig. 5. Typical hetero-skew characteristic (Fig. 5, a) leads to an increase in the deviation of the conditional variance $\pm D(X\,|\,\omega)$ with an increase of the ring rotation speed ω DBDT in the range of operating modes twice. The deviation of the estimates of conditional asymmetries $\pm A(X\,|\,\omega)$, conditional excesses $\pm E(X\,|\,\omega)$ and conditional variations $\pm Vr(X\,|\,\omega)$ from conditional mathematical expectations $M(X\,|\,\omega)$ has not significant value and increases only in the zone of rational operating modes.



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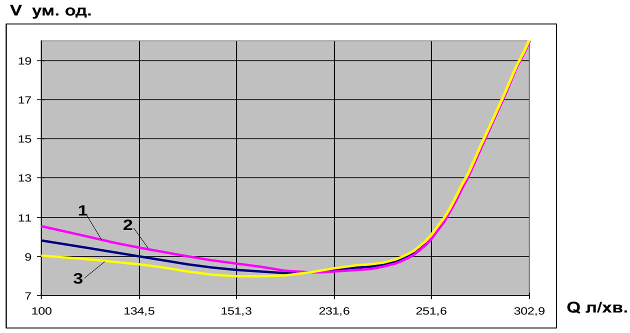

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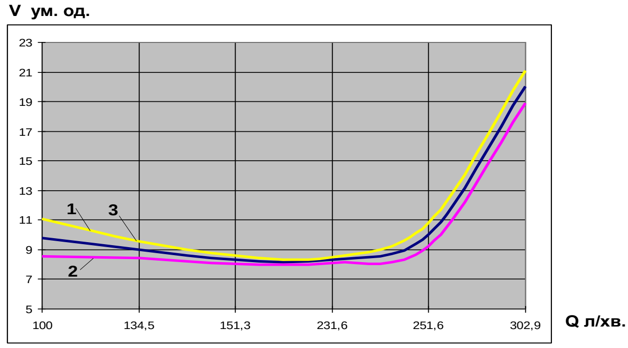

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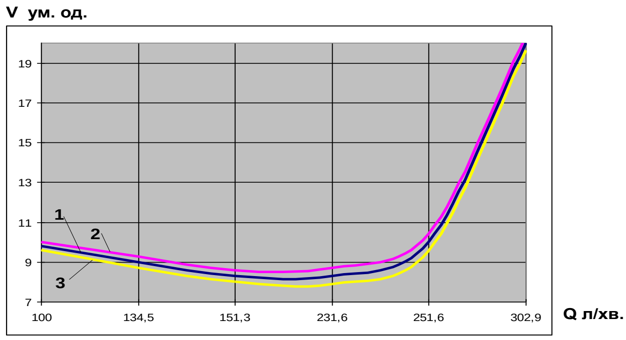
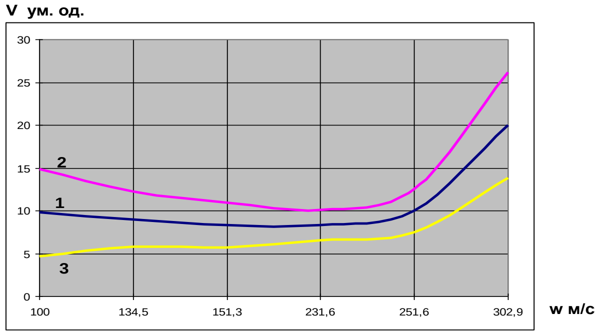


d

Fig. 1. Hetero-skew nonlinear regression models of conditional mathematical expectations $M(V\,|\,Q)$ (1) with variable conditional variances $\pm D(V\,|\,Q)$ (a), (+ this is 2, - this is 3) with conditional asymmetries $\pm A(V\,|\,Q)$ (b), with conditional excesses $\pm E(V\,|\,Q)$ (c) and conditional variations $\pm Vr(V\,|\,Q)$ (d) on the dependence on the technological parameter of the mechanical speed of drilling with diamond crowns V on the consumption of the flushing fluid Q



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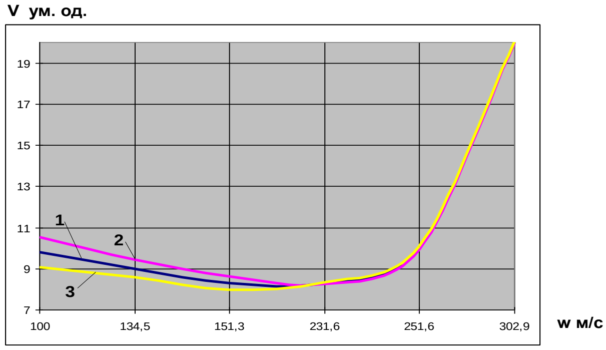

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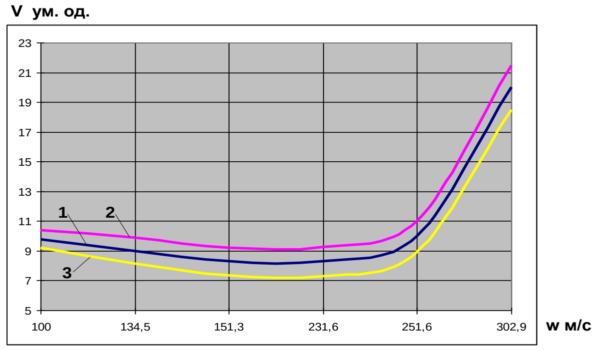

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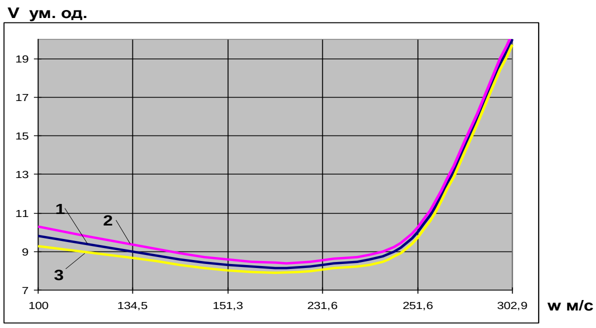
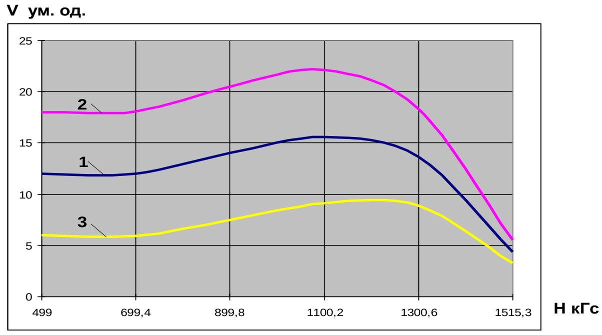


d

Fig.2. Hetero-skew nonlinear regression models of conditional mathematical expectations $M(V\,|\,\omega)$ *(1) with variable conditional variances* $\pm D(V\,|\,\omega)$ *(a), with conditional asymmetries* $\pm A(V\,|\,\omega)$ *(b), with conditional excesses* $\pm E(V\,|\,\omega)$ *(c) and conditional variations* $\pm Vr(V\,|\,\omega)$ *(d) on the dependence of the technological parameter of the speed on drilling with diamond crowns* V *on the rotation speed* ω *of DBDT.*



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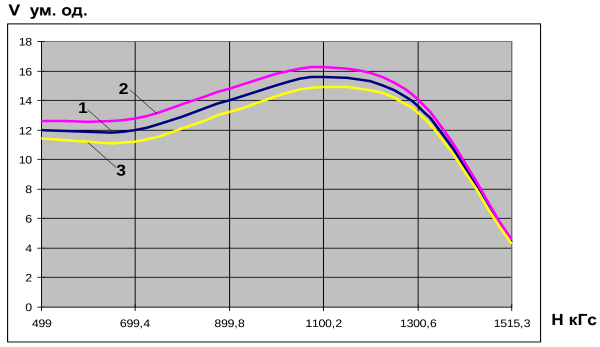

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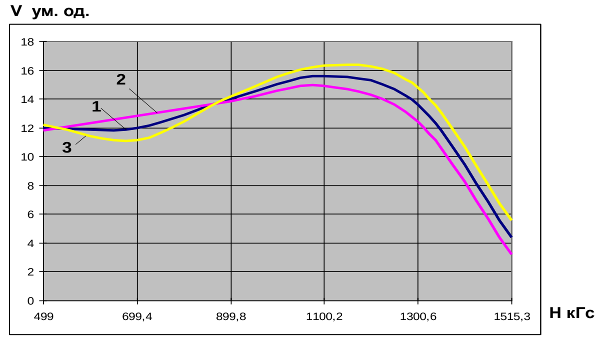

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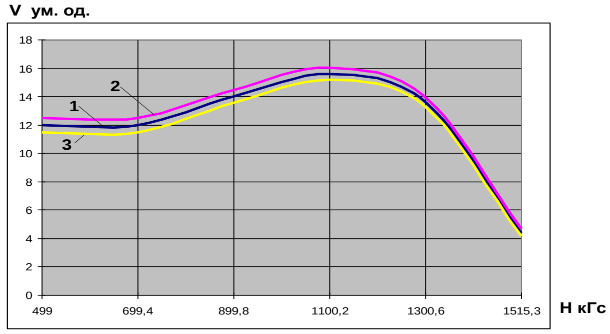


d

Fig. 3. Hetero-skew nonlinear regression models of conditional mathematical expectations $M(V\,|\,H)$ *(1) with conditional variances* $\pm D(V\,|\,H)$ *(a), with conditional asymmetries* $\pm A(V\,|\,H)$ *(b), conditional excesses* $\pm E(V\,|\,H)$ *(в) and conditional variations* $\pm Vr(V\,|\,H)$ *(d) depending on the technological parameter of the mechanical speed of drilling with diamond crowns* V *on the loading parameters* H *on DBDT*

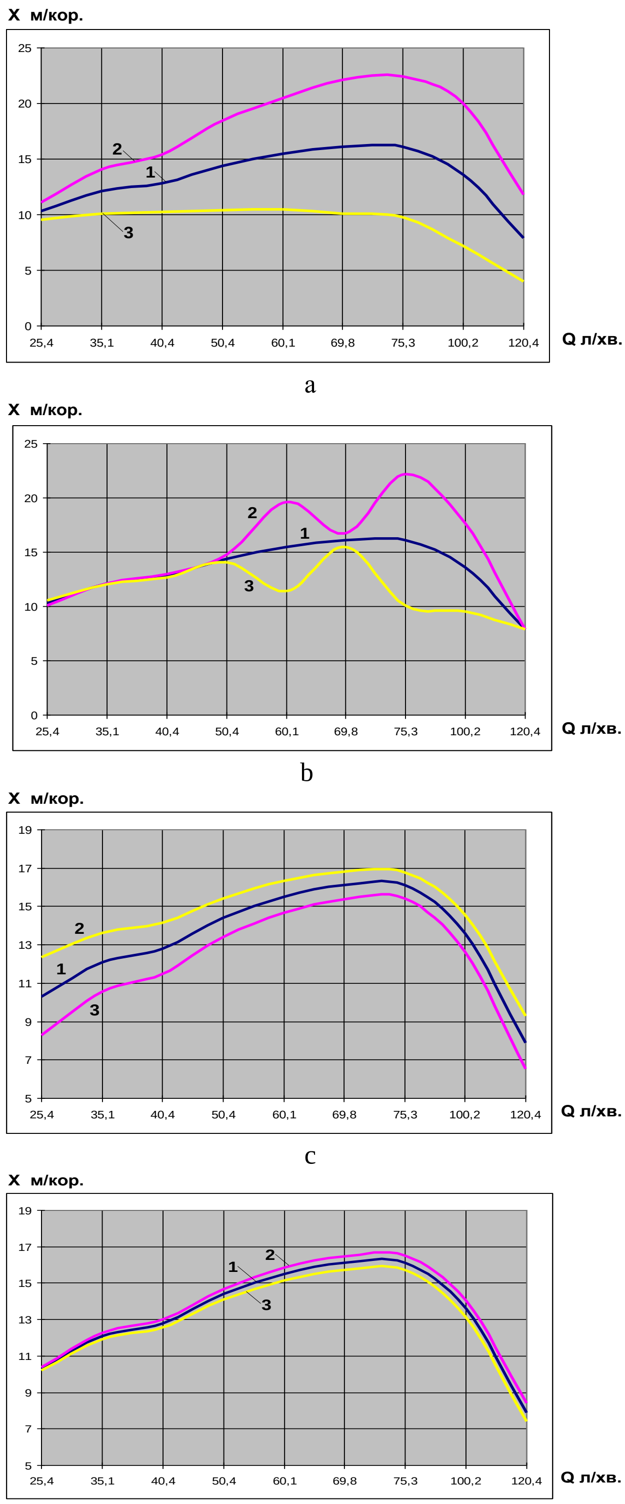


Fig. 4. Hetero-skew nonlinear regression models of conditional mathematical expectations $M(X\mid Q)$ *(1) with conditional variances* $\pm D(X\mid Q)$ *(a), conditional asymmetries* $\pm A(X\mid Q)$ *(b), conditional excesses* $\pm E(X\mid Q)$ *(c) and conditional variations* $\pm Vr(X\mid Q)$ *(d) depending on the technical parameter of driving on the diamond crown* X *on the consumption of the flushing fluid* Q

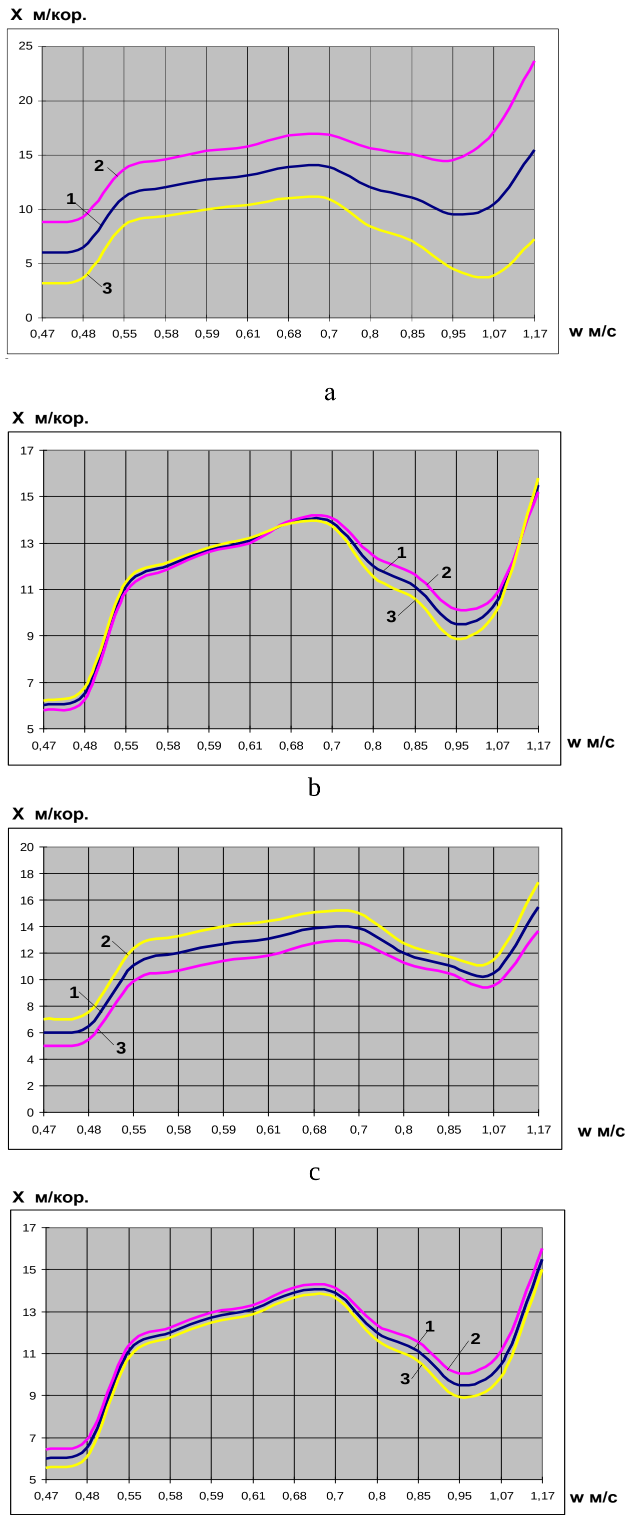
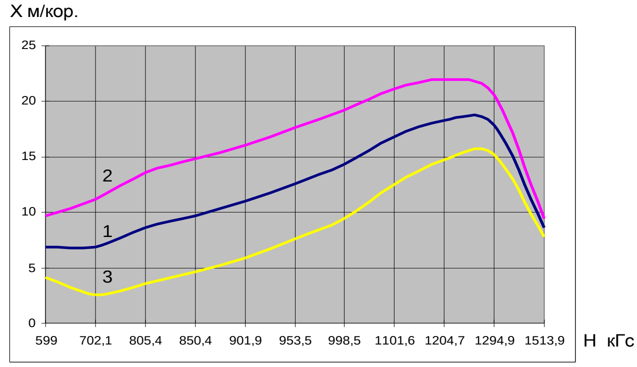
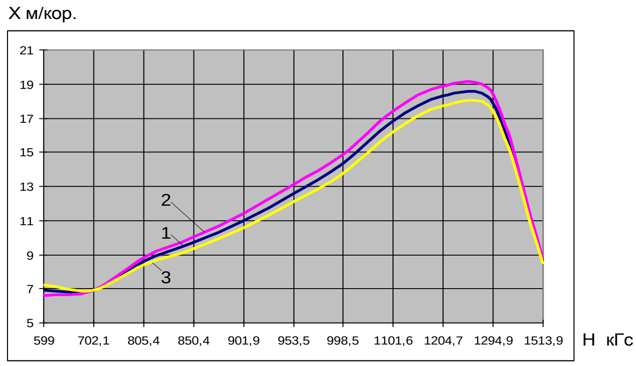


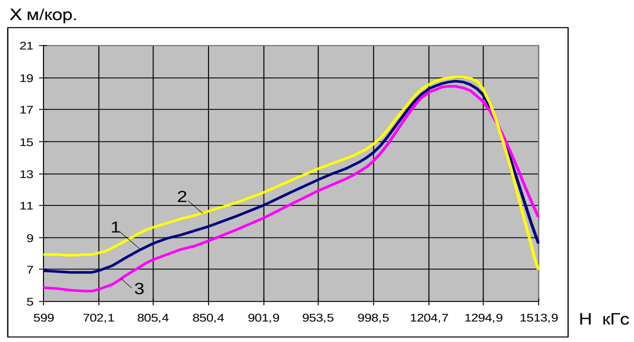
Fig.5. Hetero-skew nonlinear regression models of conditional mathematical expectations $M(X\mid\omega)$ *(1) with conditional variances* $\pm D(X\mid\omega)$ *(a), with conditional asymmetries* $\pm A(X\mid\omega)$ *(b), conditional excesses* $\pm E(X\mid\omega)$ *(c) and conditional variations* $\pm Vr(X\mid\omega)$ *(d) of the dependence of the technical parameter of driving on the diamond crown* X *on the ring rotation speed* ω *of DBDT*



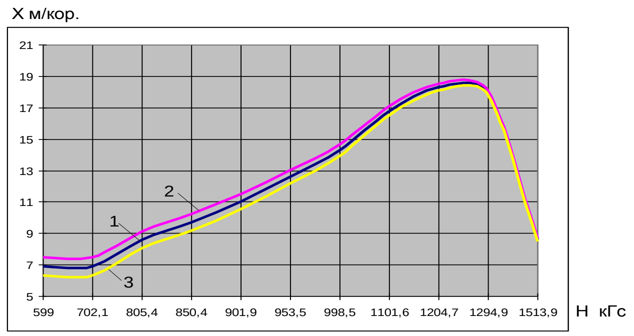
a



б



в



d

Fig.6. Hetero-skew nonlinear regression models of the conditional mathematical expectations $M(X \mid H)$ *(1) with conditional variances* $\pm D(X \mid H)$ *(a), with conditional asymmetries* $\pm A(X \mid H)$ *(b), conditional excesses* $\pm E(X \mid H)$ *(c) and conditional variations* $\pm Vr(X \mid H)$ *(d) of the dependence of the 6echnical parameter of driving on the diamond crown* X *on the loading parameters* H *on DBDT*

However, the data of the dependences (Fig. 5) have five characteristic zones each of which can be attributed to the homoscetic with an appropriate tolerance (0.47 - 0.48, 0.48 - 0.55, 0.55 - 0.1, 0.1 - 1.0, 1.0 - 1.11 м/с). Inh general, the different levels of deviations of the conditional variances $\pm D(X \mid \omega)$, conditional asymmetries $\pm A(X \mid \omega)$, conditional excesses $\pm E(X \mid \omega)$ and conditional variations $\pm Vr(X \mid \omega)$ in each of the given zones characterizes the general dependence as heteroskedic with sharp changes of directions.

Heteroskedic nonlinear regression models of conditional mathematical expectations $M(X \mid H)$ (1) of the dependence of the technical parameter of driving on the diamond crown X on the loading parameters H on DBDT with conditional variances $\pm D(X \mid H)$, conditional asymmetries $\pm A(X \mid H)$, conditional excesses $\pm E(X \mid H)$ and conditional variations $\pm Vr(X \mid H)$ are presented in Fig. 6 and have three characteristic zones (600 - 700, 700 - 1250, 1250 - 1513 kGs).

All characteristics tend to decrease the deviation with an increase of loading H on DBDT. Moreover, in the pre-extremity zone they to a lesser degree and in the post-extremity zone to a bigger degree can be approximated by linear dependencies. Characteristic are relatively small deviations of conditional asymmetries $\pm A(X \mid H)$ and conditional variations $\pm Vr(X \mid H)$ from the value $M(X \mid H)$ throughout the dependence, as well as minimization of these variations in the extreme zone of rational operating modes (1150 – 1300 kGs).

Practical value

Increasing the efficiency of the control processes by technological processes of drilling complexes in automated control systems is possible due to an increase of the amount of information support and determination of the real conditions of operation of drill bits and diamond tools, the significance of the impacts of factors such as the frequency of the vibrations of the drilling column, the frequency of interlaying of different rocks and methods for controlling the parameters of the drilling. Their influence on the drill bits and diamond tools leads to the phenomena of polishing, burning and grabbing the latter, and that significantly reduces the technical and economic performance of the drilling complex. Therefore, an increase in information provision due to the dependencies presented in the article has a significant practical value.

Conclusions and Perspectives

Thus, the definitions and analysis of the specified conditional-moment characteristics of the drilling with diamond crown allows us to establish a number of deep information regularities that reveal internal linear and nonlinear connections between the basic parameters in different operating modes of DC. It expands and deepens the information provision of ACS TP DC and leads to an increase in the accuracy and reliability of the definition of operational technological and technical states of the latter and, accordingly, improves the efficiency of automation of the process of control of the driving the boreholes. Undoubtedly, the application of the above-mentioned conditional-moment characteristics to other MEMC will allow to reveal in their accompanying signals additional deep information connections as well, and that will positively affect the quality indicators of automation of control processes in them.

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