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CONSTRUCTION PRINCIPLES OF ROLLER-BIT DRILLING RIGS DRIVE SYSTEMS FOR KRYVYI RIH QUARRIES

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The research of the study is to analyze, develop, and optimize the structural and functional principles of drilling rig drive systems to ensure efficient energy transfer, resistance to dynamic loads, adaptation to variable drilling conditions, and integration of control systems to improve drilling performance and safety.

The research was carried out on the basis of: analysis of technical documentation and standards – regulatory and technical documentation on the requirements for the design and operation of drive systems of drilling rigs was used; review of existing technical solutions – a comparative analysis of modern types of drives used in drilling rigs for various purposes; modeling and calculations – mathematical modeling of drive systems, taking into account loads, speeds and efficiency; energy efficiency and reliability – the principles of construction are considered, taking into account optimal energy consumption, automation capabilities and increased reliability of drives.

The application of the defined principles makes it possible to create a new generation drilling rig with increased reliability and durability due to the adaptation of design solutions to the difficult mining and geological conditions of Kryvyi Rih (abrasive rocks, vibration loads, dust); to increase energy efficiency by introducing frequency regulation of electric drives, optimizing the operating modes of feed, rotation and lifting drives; modularization and unification of drive units, which simplified the maintenance, repair and modernization of drilling rigs in the field; integration of automated control systems, which allowed for adaptive control of drilling parameters and reduced equipment downtime; increase in drilling process productivity, which is ensured by dynamic stability of drives, feed accuracy and torque, which is especially important for deep drilling in hard rocks of Kryvbas.

Keywords: *energy efficiency, electric drive, hydraulic drive, rod feed, roller cutter bit.*

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

Метою дослідження є аналіз, розроблення та оптимізація структурних і функціональних принципів побудови приводних систем бурового верстата для забезпечення ефективної передачі енергії, стійкості до динамічних навантажень, адаптації до змінних режимів буріння, а також інтеграції систем керування для підвищення продуктивності та безпеки бурових робіт.

Дослідження здійснено на підставі: аналізу технічної документації та стандартів – використано нормативно-технічну документацію щодо вимог до конструкції та експлуатації приводних систем бурових установок; огляду існуючих технічних рішень – проведено порівняльний аналіз сучасних типів приводів, що застосовуються в бурових верстатах різного призначення; моделювання та розрахунків – здійснено математичне моделювання роботи приводних систем з урахуванням навантажень, швидкісних режимів та ККД; енергоефективності та надійності – розглянуто принципи побудови з урахуванням оптимального енергоспоживання, можливостей автоматизації та підвищення надійності приводів.

Використання визначених принципів дає змогу створити буровий верстат нового покоління з підвищеними надійністю та довговічністю завдяки адаптації конструктивних рішень до важких гірничо-геологічних умов Кривбасу (абразивні породи, вібраційні навантаження, запиленість); підвищити енергетичну *ефективність за рахунок упровадження частотного регулювання електроприводів, оптимізації режимів роботи приводів подачі, обертання і підйому; здійснити модульність та уніфікацію вузлів приводів, що спростило обслуговування, ремонт і модернізацію бурових установок у польових умовах; інтеграцію автоматизованих систем керування, що дало змогу реалізувати адаптивне регулювання параметрів буріння та зниження простоїв обладнання; підвищити продуктивність бурового процесу, що забезпечується за рахунок динамічної стабільності приводів, точності подачі та крутного моменту, що особливо актуально для глибокого буріння у твердих породах Кривбасу.*

Ключові слова: *енергоефективність, електропривод, гідропривод, подача ставу, шарошкове долото.*

Introduction. In modern engineering, drilling rigs occupy an important place among the equipment that ensures efficient mining, geological exploration and other types of underground operations. One of the key elements of a drilling rig is the drive system, which ensures rotation, translational movement and adjustment of the working bodies, thereby determining the productivity, reliability and economic efficiency of the entire drilling rig.

Drilling rig drive systems are characterized by a complex structure and high requirements for performance parameters: they must withstand heavy loads, provide precise control, adapt to changing operating conditions, and have high efficiency. Depending on the purpose and operating conditions, different types of drilling rigs are used in the design of drilling rigs: electric, hydraulic, pneumatic and combined. Each of these types has its own advantages, disadvantages, and areas of application.

The purpose of this article is to analyze the basic principles of building drilling rig drive systems, determine the factors that influence the choice of design solutions, and review current trends in the design and modernization of such systems. Particular attention is paid to the relationship between the functional requirements for the drive and its technical characteristics, which ensure the efficient operation of drilling equipment under conditions of increased load and aggressive environment.

The systems of automatic control of the rotator and descent-lifting operations are three-circuit and five-circuit, respectively [1, 2]. The increase in the number of control loops, as compared to the general industrial drive, is explained by technological features and opportunities that arise due to the use of a faster transistor AC drive instead of a thyristor DC drive [3].

Analysis of publications. It has been established [4, 5] that with increasing bandwidths of control loops in transistorized AC drive, not only traditional di-namic links, but also additional transfer functions due to elastic properties of the drilling rig itself, hydro- and rope-polystyle systems are included in the control loop objects. In the investigated drive systems, the control loop of each parameter (coordinate) contains, as a rule, not only one "large" time constant compensated by the regulator action, but also a fractional-rational function with time constants quite commensurate with the allocated "large" time constant, which significantly complicates the system synthesis and does not allow the use of uniform control algorithms [6–8].

Objective of the study. We will consider the influence of an additional dynamic link in the control loops by correcting the transfer functions of the loop regulators without significantly changing the dynamic characteristics of the classical regulators of the general industrial drive.

Research results. Additional dynamic links in control loops are described by fractional-rational functions with high degrees. The characteristic frequencies of additional transfer functions are less than the cutoff frequency of the corresponding control loop, so they significantly affect the dynamics of the control process. The generalized structural diagram of the control object is represented as follows

$$W_o(p) = W_{okn}(p) \cdot \frac{\sum a_{mn} \cdot p^m}{\sum b_{mn} \cdot p^m},$$

where $W_{okn}(p)$ – transfer function of the compensated part of the control object; $\sum a_{mn} \cdot p^m \big/ \sum b_{mn} \cdot p^m$ – transfer function of the uncompensated part of the control object, represented as a fractional-rational function.

The control object is structurally divided into two links – compensated and uncompensated by the classical regulator parts. The compensated part is chosen as a dynamic link with one explicitly expressed "large" time constant not higher than the second order. Then the processes in the loop are well corrected by the regulator with PID characteristic [6].

The required control laws for the investigated rotary and downhill drives are determined by the technological peculiarities considering the restrictions imposed on the parameters of electrical and mechanical parts of the drive system. Restrictions are imposed on the parameters of mechanical energy flow generated in the bottom-hole area by the roller cone bit, the values of accelerations and shocks allowed by the hydraulic and rope-poly-resistance systems, derrick design, overloading capacity of motors, their permissible heating, etc. The above-mentioned main factors together with the type of disturbance (by disturbance channels for the rotator drive and task – for the drive of downhole operations) determine the permissible laws of change of both the main (external or output) and all intermediate coordinates of the drive system. Determination of algorithms of regulators functioning is made by means of sequential correction of dynamic characteristics of each separate taken contour, starting from the fastest – interna $m = 1$, to the most external loop $m = n$ with the minimum fast-action. Optimization means bringing the dynamic parameters of a closed loop into compliance with the constraints imposed on the quality of the transient process.

The generalized transfer function of the optimized loop object under the assumptions made can be written as follows [7, 8]:

$$W_{on}(p) = W_{okn}(p) \cdot W_{onn(p)} = $$
$$= \frac{2 \cdot \xi_n' \cdot T_n' \cdot p + 1}{T_n^2 \cdot p^2 + 2 \cdot \xi_n \cdot T_n \cdot p + 1} \cdot \frac{\sum a_{mn} \cdot p^m}{\sum b_{mn} \cdot p^m},$$

where T_n, T_n' – time constants; ξ_n, ξ_n' – damping coefficients.

Here, the dynamic link $W_{okn}(p)$ corresponds to the links whose action is compensated by the controller. The second dynamic link is represented by a fractional-rational expression whose action cannot be suppressed by the classical *PID* controller due to the complexity of the compensation algorithm. If we refer the time constants of the fractional-rational transfer function to small uncompensated time constants of the control loop, its performance will be significantly reduced, which will negatively affect the dynamics of the entire control system. By selecting a small uncompensated time constant of the optimized control loop, we determine its permissible limit of fast performance.

In the considered drive systems, the time constants of the additional dynamic loop link are commensurate with large "compensated" time constants, so they significantly affect the control dynamics.

In the control circuits of the active component of current, pressure in the hydraulic system of the drive of down-lifting operations, as well as in the control of the active component of current of the rotator drive, the forcing effects of the circulating counter-EMF and negative feedback in the hydraulic system are affected. Uncompensated zeros in the transfer functions appear in these circuits. In this case, the loop controller with *PID* characteristic does not bring the transfer function of the closed loop in compliance with the requirements. To compensate for the additional zero in the transfer function, it is necessary to introduce one more zero pole into the *PID* controller, which eventually leads to the appearance of regulators with PID^2 – dynamic characteristic. Therefore, even in those cases when the characteristic frequencies of the additional transfer functions of the control object do not fall within the bandwidths of the marked loops, the regulators of these control loops must have ф PID^2 – dynamic characteristic

$$W(p) = \frac{T_n^2 \cdot p^2 + 2 \cdot \xi_n \cdot T_n \cdot p + 1}{p^2 \cdot T_0},$$

where T_0 – constant controller integration time.

With this setting of the current and pressure regulators, the static closed loop error tends to zero.

To suppress the elastic oscillations of the pack, additional regulating links should be included in parallel with the main regulators or their action should be recalculated to the output of the current regulator. The latter is preferable, since the corrective action is applied to the fastest-acting circuit. Algorithms of regulators operation at such method of oscillatory processes pressure in the control system are defined in the following way.

In order to compensate for additional transfer functions, it is necessary to include in parallel to each basic classical regulator a pre-additional regulator with transfer function

$$W_{n(p)=} \frac{1}{p \cdot T_O \cdot W_{okn}(p)} \cdot \frac{\sum (b_{mn} - a_{mn}) \cdot p^m}{\sum a_{nm} \cdot p^m}.$$

At such compensation one can obtain an additional regulator with polynomials of numerator and denominator, reaching up to sixth powers, in the loop of current of drive of descent-lifting operations, up to fourth powers – in the loop of speed of motor of drive of descent-lifting operations and in the loop of current of drive of rotation, that complicates their realization in the classical form.

If we bring the action of all additional regulators to the output of the internal regulator, we can find one regulator that covers the classical regulators in parallel and replaces the action of these regulators. In this case, the algorithm of operation of one regulator

$$W'(p) = \frac{1}{p \cdot T_{on} \cdot W_{okn}(p)} \cdot \frac{\sum (b_{mn} - a_{mn}) \cdot p^m}{\sum a_{nm} \cdot p^m} \times$$
$$\times \prod_{k=n-1}^{1} \left(\frac{1}{p \cdot T_{ok} \cdot W_{okk}(p)} \cdot \frac{\sum b_{nk} \cdot p^n}{\sum a_{nk} \cdot p^n} \right)$$

becomes more complex than the algorithm of each regulator separately.

All algorithms for correction of dynamic processes contain derivatives of at least the second degree from the mismatch signal, which, in the presence of noise, will affect the performance of such compensation. Besides, the change of control object parameters leads to instability of characteristic frequencies of drill rig oscillations, so it is possible to adjust correction algorithms only in one working point of contours. Changing the number of connected drill rods leads not to compensation of elastic oscillations by additional correcting links, but to increase of oscillation of the control system. Therefore, algorithms of dynamics correction should have the properties of adaptation to the variable parameters of the control object.

In connection with the above, we solve the problem of compensation of elastic oscillations in the current, pressure and speed circuits by applying the principles of fuzzy control of complex objects, to which we refer the electric drives of lowering and lifting operations and the rotator of the drilling machine in the presence of elastic links in the transmission.

The approach based on fuzzy set theory has distinctive features: in addition to numerical variables, fuzzy quantities, so-called "linguistic" variables, are used; simple relations between variables are described by fuzzy statements; complex relations are described by fuzzy algorithms.

This approach provides approximate, but at the same time effective ways of describing the behavior of systems so complex that adaptive controllers with polynomials of high degrees in both numerator and denominator are required to correct their dynamics.

Conclusions. Thus, because of the conducted researches it is established that:

– additional fuzzy corrective regulators should be introduced into those control loops of drive systems, where natural frequencies of additional links of the control object are less than the loop cut-off frequency;

– in the absence of free component in the signal of the controlled coordinate the fuzzy regulator does not affect the operation of the classical loop regulator.

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