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The scientific journal News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences has been indexed in the international abstract and citation database Scopus since 2016 and demonstrates stable bibliometric performance.

The journal is also included in the Emerging Sources Citation Index (ESCI) of the Web of Science platform (Clarivate Analytics, since 2018).

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Indexing in Scopus and Web of Science ensures high international visibility of publications, promotes citation growth, and reflects the editorial board's commitment to publishing relevant, original, and scientifically significant research in the fields of geology and technical sciences.

«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылымиметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

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DYNAMICS OF THE ELASTIC COUPLING BLOCK IN THE DRILLING REGULATOR DURING GEOLOGICAL EXPLORATION

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Abstract. *Relevance.* The paper considers a method for regulating the axial load on a chisel when drilling exploration wells using an elastic lever clutch with centrifugal pads, which is used as part of the drive of the chisel feed regulator and performs the function of a mechanical sensor for axial load on the chisel. *Objective.* The purpose of this study is to construct a mathematical model of the motion of a centrifugal pad in an elastic lever clutch, integrate the resulting differential equation, determine the coordinates, speeds and accelerations of the pad and the pressure on the walls of the cutout of the clutch, depending on the design parameters and operating mode. *Methods.* The dynamics of an elastic coupling block in a drilling regulator used for drilling exploration wells is considered, namely, differential equations of motion of the block are compiled taking into account the action of centrifugal force, spring elasticity and medium resistance. The equations are integrated numerically for different conditions. The dependences of the coordinate, speed and acceleration of the pad movement and pressure on the walls of the coupling cutout on time and design parameters are determined. *Results.* The results of numerical integration have shown that the motion of the centrifugal pad is oscillatory in nature with a gradual attenuation of vibrations and transition to a steady state. *Conclusions.* At the initial stage, significant amplitudes of deviations and velocities are observed, which is due to the inertia of the system and the impact of the initial disturbance. In steady state, the deflection angle stabilizes, which corresponds to a stable load on the chisel. The practical significance of the study lies in the possibility of using the obtained dependencies in the design of couplings and bit feed control systems, as well as optimizing the drilling modes of exploration wells.

Keywords: drilling of exploration wells, axial load on the chisel, lever clutch, centrifugal pads, differential equations, flow control, pad dynamics

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ГЕОЛОГИЯЛЫҚ БАРЛАУ КЕЗІНДЕ БҰРҒЫЛАУ РЕТТЕГІШІНДЕГІ СЕРПІМДІ МУФТА ҚАЛЫБЫНЫҢ ДИНАМИКАСЫ

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Аннотация. *Өзектілігі.* Жұмыста өте өзекті болып табылатын геологиялық барлау ұңғымаларын бұрғылау кезінде қашауды беру реттегішінің жетегі құрамында қолданылатын және қашауға осьтік жүктеменің механикалық датчигі қызметін атқаратын орталықтан тепкіш қалыптары бар серпімді тұтқалы муфтаны пайдалана отырып, қашаудың осьтік жүктемесін реттеу әдісі қарастырылды. *Мақсаты.* Бұл зерттеудің мақсаты серпімді тұтқалы муфтаның құрамында центрифугалық қалыптың қозғалысының математикалық моделін құру, алынған дифференциалдық теңдеуді интегралдау, қалыптың координаттарын, жылдамдықтары мен үдеулерін және конструкция параметрлері мен жұмыс режиміне байланысты муфтаның қиық қабырғаларына қысымды анықтау болып табылады. *Әдістері.* Геологиялық барлау ұңғымаларын бұрғылау кезінде қолданылатын бұрғылау реттегішіндегі серпімді муфта қалыбының динамикасы қарастырылды, атап айтқанда орталықтан тепкіш күштің, серіппенің серпімділік күшінің және ортаның кедергісінің әсерін ескере отырып, қалып қозғалысының дифференциалдық теңдеулері жасалды. Теңдеулер әртүрлі шарттар үшін сандық түрде интегралданды. Қалыптың координатасының, жылдамдығының және қозғалысының үдеуінің және муфтаның қабырғаларына қысымның құрылымның уақыты мен параметрлеріне тәуелділігі анықталды. *Нәтижелері.* Сандық интегралдау нәтижелері орталықтан тепкіш қалыптың қозғалысы тербелістердің біртіндеп әлсіреуімен және тұрақты режимге өтуімен тербелмелі екенін көрсетті. *Қорытынды.* Бастапқы кезеңде ауытқулар мен жылдамдықтардың айтарлықтай амплитудасы байқалады, бұл жүйенің инерциясына және бастапқы әрекеттің әсеріне байланысты. Тұрақты режимде ауытқу бұрышы тұрақтандырылады, бұл қашаудың тұрақты жүктемесіне сәйкес келеді. Зерттеудің практикалық маңыздылығы муфталар мен қашау беруді реттеу жүйелерін жобалау кезінде алынған тәуелділіктерді пайдалану, сондай-ақ геологиялық барлау ұңғымаларын бұрғылау режимдерін оңтайландыру мүмкіндігі болып табылады.

Түйін сөздер: геологиялық барлау ұңғымаларын бұрғылау, қашауға осьтік жүктеме, иінтіректі муфта, орталықтан тепкіш қалыптар, дифференциалдық теңдеулер, беруді реттеу, қалып динамикасы

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ДИНАМИКА КОЛОДКИ УПРУГОЙ МУФТЫ В БУРОВОМ РЕГУЛЯТОРЕ ПРИ ГЕОЛОГОРАЗВЕДКЕ

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Аннотация. *Актуальность.* В работе рассматривается метод регулирования осевой нагрузки на долото при бурении геологоразведочных скважин с использованием упругой рычажной муфты с центробежными колодками. Муфта входит в состав привода регулятора подачи долота и выполняет функцию механического датчика осевой нагрузки. Исследование динамики её рабочих элементов необходимо для повышения точности регулирования подачи, устойчивости процесса бурения и надёжности бурового оборудования. *Цель.* Разработать математическую модель движения центробежной колодки упругой рычажной муфты, выполнить численное интегрирование полученного дифференциального уравнения и определить координату, скорость и ускорение колодки, а также давление на стенки выреза муфты в зависимости от конструктивных параметров и режима работы. *Методы.* Исследована динамика колодки упругой муфты бурового регулятора, применяемого при геологоразведочном бурении. Составлены дифференциальные уравнения движения колодки с учётом действия центробежной силы, силы упругости пружины и сопротивления среды. Уравнения проинтегрированы численно при различных значениях конструктивных и режимных параметров. Определены временные зависимости координаты, скорости и ускорения колодки, а также давления на стенки выреза муфты. *Результаты.* Результаты численного интегрирования показали, что движение центробежной колодки имеет колебательный характер. С течением времени амплитуда колебаний постепенно уменьшается, после чего система переходит в установившийся режим. На начальном этапе зарегистрированы значительные амплитуды отклонения и скорости движения колодки, обусловленные инерционностью системы и воздействием начального возмущения. В установившемся режиме угол отклонения колодки стабилизируется, что соответствует устойчивому значению осевой нагрузки на долото. *Выводы.* Разработанная математическая модель позволяет оценивать динамические характеристики центробежной колодки упругой рычажной муфты с учётом конструктивных параметров и режима работы бурового регулятора. Полученные зависимости могут применяться при проектировании и совершенствовании упругих муфт, систем регулирования подачи долота и выборе рациональных режимов бурения геологоразведочных скважин.

Ключевые слова: бурение геологоразведочных скважин, осевая нагрузка на долото, рычажная муфта, центробежные колодки, дифференциальные уравнения, регулирование подачи, динамика колодки

Introduction. The oil and gas industry occupies a key place in the economy of Kazakhstan, being the main source of state budget revenues and a driver of the country's economic growth. The rich oil and gas reserves concentrated in fields such as Tengiz, Kashagan and Karachaganak ensure Kazakhstan's status as one of the world's leading hydrocarbon producers (Niyazbekova et al., 2018).

Oil and gas exports make up a significant part of the country's foreign trade balance, attracting foreign investment and contributing to infrastructure development. The oil and gas sector provides jobs for a significant part of the population, not only directly, but also through related industries such as transportation, processing, engineering and service maintenance.

Drilling of exploration wells is a complex of operations for opening and exploring the subsurface in order to search, explore and evaluate mineral deposits (oil, gas, ores, groundwater, etc.).

The main objectives of drilling exploration wells are to determine the geological structure of the section; to identify and delineate deposits; to take core and fluid samples; to clarify reserves and their categories; to obtain data for the design of production wells. Types of exploration wells are divided by purpose into exploratory; exploratory; estimated; parametric. In terms of depth, exploration wells can be shallow (up to 300 m); medium (300-1500 m); deep (more than 1,500 m), and according to the drilling method - rotary; turbine; electric drilling; shock-rope (less often) (Mikheev, 2021).

The main stages of drilling exploration wells include the preparatory stage, which includes geological and geophysical justification; selection of the drilling point; site construction. The next stage is the drilling process itself, which includes drilling through the barrel; casing fastening; and rinsing with drilling fluid. Geological support is associated with core sampling; geophysical surveys (GIS), as well as a description of the section. Testing and conservation include reservoir testing; well liquidation or conservation (Juraev, 2016).

The features of exploration drilling are increased requirements for core safety; frequent lithology changes; drilling in difficult conditions (mountainous areas, slopes, as in Mangystau); strict environmental requirements (Grakov, 2018).

The process of drilling exploration wells requires strict control of the axial load on the chisel to ensure sustainable rock destruction, prolong the service life of the drilling tool and prevent accidents. One of the key factors determining the drilling efficiency of exploration wells is the correct distribution of the axial force transmitted from the drill string to the bit. Excessive load can lead to premature wear of the chisel and complications in the well, while insufficient load reduces the mechanical drilling speed of exploration wells (Bai, 2021).

Automatic and semi-automatic bit feed control systems based on the use of various sensors and actuators are increasingly being used in modern drilling rigs. However, in conditions of limited space, high temperature and polluted environment, the use of electronic systems is not always justified. In such cases, reliable mechanical devices capable of performing control and regulation functions without the use of complex electronics come to the fore.

One of these solutions is the use of an elastic lever clutch with centrifugal pads, which is part of the drive of the chisel feed regulator. This coupling performs a dual function: on the one hand, it participates in the transmission of rotation, and on the other, it acts as a mechanical axial load sensor. The principle of operation is based on the movement of the pads under the action of centrifugal force, balanced by the elasticity of the lever elements. Changing the position of the pads allows you to get information about the load, adjust the flow of the drill string.

The purpose of this study is to construct a mathematical model of the motion of a centrifugal pad in an elastic lever clutch, integrate the resulting differential equation, determine the coordinates, speeds and accelerations of the pad and the pressure on the walls of the cutout of the clutch, depending on the design parameters and operating mode.

The scientific novelty of the work consists in taking into account a complex of factors affecting the dynamics of the shoe, including the elasticity of the lever, the force of the resistance of the medium and the change in the radius of the trajectory.

The practical significance of the study lies in the possibility of using the obtained dependencies in the design of couplings and bit feed control systems, as well as optimizing the drilling modes of exploration wells.

Materials and research methods. The analysis of existing scientific and engineering solutions presented in educational and scientific sources devoted to the regulation of axial load on the chisel is carried out. Special attention is paid to the works considering the dynamics of centrifugal clutch pads. To simulate the behavior of the pads during movement, a differential equation has been compiled describing the dynamics of their movement along the cutout of the coupling. The equation takes into account parameters such as spring stiffness and rotational speed. This allows you to estimate the trajectory of the movement. After the differential equation was compiled, it was integrated to obtain analytical and numerical solutions describing the trajectory, speed and acceleration of the pad movement and pressure on the walls of the coupling cutout, depending on the design parameters and operating mode.

Discussion of the results. The article was discussed in front of the faculty of Atyrau University of Oil and Gas named after Safi Utebayev and recommended for publication.

An elastic lever clutch with centrifugal pads is a mechanical device designed to automatically regulate the flow of a drill string by converting rotational motion into controlled axial movement. This coupling is part of the drive of the bit feed regulator and plays an important role in maintaining optimal axial load on the bit during drilling of exploration wells (Fedin, 2013).

The main elements of the coupling are:

– Levers pivotally mounted on the drive shaft and connected to elastic elements (springs);

– Centrifugal pads mounted on the ends of levers that move radially when the shaft rotates;

– Springs providing a return force balancing the action of centrifugal force;

The cutout of the coupling is the inner surface of the fixed part of the coupling with which the pads are in contact.;

The axial force transmission system is the elements that connect the movement of the pads with the feed mechanism of the drill string (Wu et al., 2024).

When the coupling shaft rotates, the centrifugal pads tend to move away from the axis of rotation under the action of centrifugal force. This causes the levers to rotate, and as a result, the radial position of the pads to change. The springs resist this movement, creating a balancing force (Tang et al., 2017).

When the axial load on the chisel increases, the rotational speed decreases and the centrifugal force weakens. The pads are pressed against the axis of rotation due to the action of elastic forces, and the system reacts with a corresponding increase in feed. As the load decreases, the rotation speed increases, the pads deflect outward, and the mechanism restricts the feed (Sitnikov et al., 2003).

Thus, the coupling acts as a mechanical regulator, automatically changing the feed force depending on the magnitude of the axial load and the speed of rotation. The pads, in contact with the walls of the coupling cutout, create an adjustable pressure that is proportional to their radial velocity and mass (Zhang et al., 2023).

To accurately assess the behavior of the clutch, it is necessary to consider the movement of the shoe as a function of time, taking into account the mass of the shoe, the length of the lever, the stiffness of the spring, as well as the resistance of the medium (friction, inertial forces). These factors directly affect the speed and trajectory of the pad movement and, consequently, the accuracy of feed control (Strugovets et al., 2005).

To analyze the operation of an elastic lever clutch with centrifugal pads, it is necessary to create a differential equation describing the movement of the pad as a function of time. The dynamics of the shoe is determined by the action of three main forces: centrifugal force, spring elasticity force and the resistance force of the medium (for example, friction and damping) (Sitnikov et al., 2018).

Let the centrifugal block *M*, considered as a material point, move along the cylindrical channel of the moving coupling *A* (Figure 1). Let's find the equation of the relative motion of this centrifugal block $x = f(t)$, taking the reference point *O* as the starting point.

We will also find the *x* coordinate and the pressure of the centrifugal pad on the channel wall at a given value $t = t_1$.

We will set the following data: mass of the centrifugal pad $m = 0{,}08$ kg; constant angular velocity of the coupling *A* $\omega = 6\pi$ rad/s; initial coordinate $x_o = 0{,}05$ m; projection of the initial velocity on the *x* axis $\dot{x}_o = 0$ m/s; $t_1 = 0{,}1$ s; stiffness coefficient of the spring to which the centrifugal pad is attached *M* $c = 0{,}20$ N/cm; the length of the undeformed spring $l_o = 0{,}10$ m; the coefficient of sliding friction of the centrifugal pad along the channel wall $f = 0$.

Decision. We combine the moving *Oxyz* reference frame with the rotating channel (notch) by aligning the x-axis with the trajectory of the relative motion of the centrifugal block *M*.

The rotation of this system around the x_1 axis is a portable motion for the centrifugal block *M*. The relative motion of the centrifugal block *M* is its movement along the notch. In the case where the portable motion is a uniform rotation, the relative motion of the centrifugal pad, taken as a point, is determined by the equation (Shirkavand et al., 2010)

$$m\vec{a}_r = \sum \vec{P}_i + \vec{\Phi}_e^c + \vec{\Phi}_c, \tag{1}$$

where

$\sum \vec{P}_i$ is the geometric sum of the forces applied to the centrifugal pad (point);

$\vec{\Phi}_e^c$ is the portable centrifugal force of inertia;

$\vec{\Phi}_c$ is the Coriolis force of inertia.

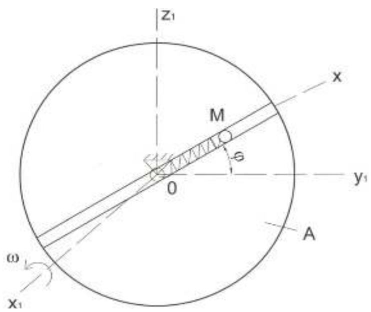

Figure 1. Model of the movement of the centrifugal pad along the cutout of the clutch: *M* – centrifugal pad; *A* – elastic lever centrifugal clutch.

Forces are applied to the centrifugal block *M*: the weight $\vec{G}$, the spring reaction $\vec{P}$ and the normal reaction of the channel wall (cutout); this reaction can be decomposed into two mutually perpendicular components N_1 and N_2. We do not take into account the force of friction, as well as the reaction of the lever, due to their lower values.

We add to the forces acting on the centrifugal block *M* the portable centrifugal force of inertia $\vec{\Phi}_e^c$ and the Coriolis force of inertia $\vec{\Phi}_c$, directed opposite to the accelerations $\vec{a}_e^c$ and $\vec{a}_c$. The acceleration direction $\vec{a}_c$ is found according to the well-known rule. Assume that the direction of the relative velocity $\vec{v}_r$ of the centrifugal pad *M* coincides with the positive direction of the *x*-axis. In this case, the Coriolis inertia force $\vec{\Phi}_c$ is perpendicular to the plane *xOz* and directed as shown in Figure 2.

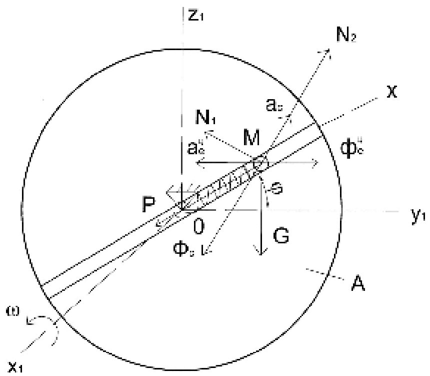

Figure 2. Forces and accelerations acting on the centrifugal pad.

The modules of inertia forces are determined by the formulas:

$$\Phi_e^c = ma_e^c = m\omega_e^2 \cdot x;$$

$$\Phi_c = ma_c = m \cdot 2\omega_e v_r \sin 90^\circ = 2m\omega\dot{x};$$

The power of elasticity: $P = c \cdot \Delta l = c \cdot (x - l_o)$.

The basic equation of the relative motion of the centrifugal block *M* in this case has the form

$$m\vec{a}_r = \vec{G} + \vec{P} + \vec{N} + \vec{\Phi}_e^c + \vec{\Phi}_c; \tag{2}$$

Let's make a differential equation of the relative motion of the centrifugal pad along the *x* axis:

$$m\ddot{x} = -P - G\sin\varphi + \Phi_e^c;$$

$$m\ddot{x} = -c(x - l_o) - mg\sin\omega t + m\omega^2 \cdot x;$$

The last equation is represented as

$$\ddot{x} - \left(\omega^2 - \frac{c}{m}\right)x = -g\sin\omega t + \frac{c}{m} \cdot l_o. \qquad (3)$$

The general solution of the obtained differential equation (3) has the form

$$x = x^* + x^{**},$$

where
x^* - the general solution of the corresponding homogeneous equation;
x^{**} - partial solution of the equation (3).
Let's make up a characteristic equation and find its roots:

$$\lambda^2 - \left(\omega^2 - \frac{c}{m}\right) = 0;$$

$$\lambda_1 = \sqrt{\omega^2 - \frac{c}{m}} = \sqrt{(6\pi)^2 - \frac{20}{0{,}08}} = 10{,}3\,\frac{1}{s};$$

$$\lambda_1 = \sqrt{\omega^2 - \frac{c}{m}} = -10{,}3\,\frac{1}{s}.$$

Then the general solution of the homogeneous equation has the form:

$$x^* = C_1 e^{10{,}3t} + C_2 e^{-10{,}3t};$$

A partial solution of the equation is found in the form:

$$x^{**} = A\cos\omega t + B\sin\omega t + Ct + D;$$

We determine the constant coefficients *A* and *B*:

$$\dot{x}^{**} = -A\sin\omega t + B\cos\omega t + C;$$

$$\ddot{x}^{**} = -A\omega^2\cos\omega t - B\omega^2\sin\omega t;$$

Calculating: $\omega^2 - \frac{c}{m} = (6\pi)^2 - \frac{20}{0{,}08} = 105{,}3\,\frac{1}{c^2};$

$$-A\omega^2 cos\omega t - B\omega^2 sin\omega t - \left(\omega^2 - \frac{c}{m}\right)[Acos\omega t + Bsin\omega t + ct + D] =$$
$$= -gsin\omega t + \frac{c}{m} l_o;$$

By $cos\omega t$: $-A\omega^2 - A\omega^2 + A\frac{c}{m} = 0$;
Means, $A = 0$.

$$-B\omega^2 - B\omega^2 + B\frac{c}{m} = -g;$$

By $sin\omega t$: $-B\omega^2 - B\omega^2 + B\frac{c}{m} = 0$;

$$B\left(2\omega^2 - \frac{c}{m}\right) = g;$$

Where from: $B = \frac{g}{2\omega^2 - \frac{c}{m}} = \frac{9{,}81}{2(6\pi)^2 - \frac{20}{0{,}08}} = 0{,}02$ m;

With a free member: $-\left(\omega^2 - \frac{c}{m}\right)D = \frac{c}{m} l_o$;

$$D = -\frac{cl_o}{m\left(\omega^2 - \frac{c}{m}\right)} = -\frac{20 \cdot 0{,}1}{0{,}08\left((6\pi)^2 - \frac{20}{0{,}08}\right)} = -0{,}24 \text{ m};$$

By t: $c = 0$;

Means: $x^{**} = 0{,}02sin\omega t - 0{,}24$.

The solution of the differential equation of the relative motion of the centrifugal block *M* takes the form:

$$x = C_1 e^{10{,}3t} + C_2 e^{-10{,}3t} + 0{,}02sin\omega t - 0{,}24;$$

$$\dot{x} = 10{,}3C_1 e^{10{,}3t} - 10{,}3C_2 e^{-10{,}3t} + 0{,}02\omega cos\omega t;$$

The integration constants C_1 and C_2 are determined using the initial conditions: at $t = 0$ $x_o = 0{,}05$ m $\dot{x}_o = 0$;

Then: $x_o = 0{,}05 = C_1 + C_2 - 0{,}24$; $C_1 + C_2 = 0{,}29$;

$$\dot{x}_o = 0 = 10{,}3C_1 - 10{,}3C_2 + 0{,}02\omega;$$

$$10{,}3(C_1 - C_2) = -0{,}02 \cdot 6\pi;$$

$$C_1 - C_2 = -\frac{0{,}02 \cdot 6\pi}{10{,}3} = -0{,}04;$$

Solving the system:

$$\begin{cases} C_1 + C_2 = 0{,}29; \\ C_1 - C_2 = -0{,}04; \end{cases}$$

$$2C_1 = 0{,}25; \; C_1 = 0{,}125;$$

$$C_2 = 0{,}29 - C_1 = 0{,}29 - 0{,}125 = 0{,}165;$$

The equation of relative motion of the centrifugal pad takes the final form:

$$x = 0{,}125e^{10{,}3t} + 0{,}165e^{-10{,}3t} + 0{,}02sin(6\pi t) - 0{,}24;$$

The speed of the relative motion of the centrifugal pad:

$$\dot{x} = 1{,}29e^{10{,}3t} - 1{,}70e^{-10{,}3t} + 0{,}38cos(6\pi t);$$

Acceleration of the relative motion of the centrifugal pad:

$$\ddot{x} = 13{,}3e^{10{,}3t} + 17{,}5e^{-10{,}3t} - 7{,}2sin(6\pi t);$$

The values of the coordinates, speeds, and accelerations of the centrifugal pad in various time values are given in Tables 1, 2, and 3.

Table 1. The coordinate $x(t)$.

t, s	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8
x, m	0,05	0,19	0,75	2,50	7,48	21,31	60,11	168,88	473,46

Table 2. Speed $\dot{x}(t)$.

t, s	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8
$\dot{x}$, m/s	-0,03	3,01	9,59	28,58	79,50	222,05	623,17	1745	4888

Table 3. Acceleration $\ddot{x}(t)$.

t, s	0	0,1	0,2	0,3	0,4	0,5	0,6	0,7	0,8
$\ddot{x}$, m/s^2	30,8	36,65	110,81	297,32	812,17	2293	6430	17989	50396

According to Tables 1,2 and 3, graphs of the coordinates, speeds, and accelerations of the centrifugal pad motion are plotted in various time values (Figure 3).

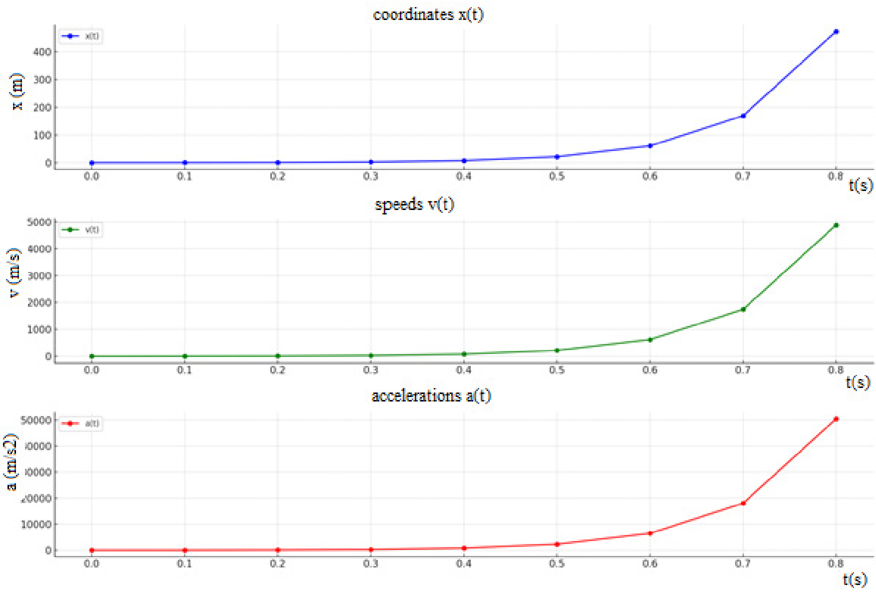

Figure 3. Graphs of coordinates, speeds, and accelerations of the centrifugal pad in various time values.

Chart analysis:

The coordinate x(t):

The graph increases exponentially, especially after t=0,3 seconds. This indicates an increasing movement with increasing displacement. The amplitude increases greatly with increasing time, which is caused by the exponential term $e^{10,3t}$.

Speed $\dot{x}(t)$:

The speed also increases rapidly, at first smoothly, then very abruptly after 0,4–0,5 seconds. This is typical for motion with exponential acceleration.

Acceleration $\ddot{x}(t)$:

Acceleration increases even faster than speed. After 0,5 seconds, it takes on very large values, indicating an increasing acceleration.

The radius of the coupling is no more than 1 m, so the pad reaches its maximum position in about 0,3-0,4 seconds, which corresponds to a speed of 28,58-79,50 m/s.

To determine the reaction of the cutout wall $\bar{N}$ at $t = t_1 = 0,1$ s, we express the vector equation in projections on the *y* axis.

Given that the vector $\bar{a}_r \perp$ of this axis, we get:

$$0 = -Gcos\varphi - \Phi_c + N;$$

From this equation we find N:

$$N = G\cos\varphi + \Phi_c = mg\cos\omega t + 2m\omega\dot{x};$$

To obtain numerical values, it is necessary to determine the coordinate x_1 and the projection of the relative velocity of the point $\dot{x}_1 = v_e$, corresponding to the value $t_1 = 0{,}1$ s.:

$$x_1 = 0{,}125e^{10{,}3\cdot 0{,}1} + 0{,}165e^{-10{,}3\cdot 0{,}1} + 0{,}02\sin(6\pi\cdot 0{,}1) - 0{,}24 = 0{,}17 \text{ m};$$

$$\dot{x}_1 = 1{,}29e^{10{,}3\cdot 0{,}1} - 1{,}7e^{-10{,}3\cdot 0{,}1} + 0{,}38\cos(6\pi\cdot 0{,}1) = 3{,}01 \text{ m/s};$$

Then:

$$N = mg\cos\omega t_1 + 2m\omega\dot{x}_1 = 0{,}08\cdot 9{,}81\cos(6\pi\cdot 0{,}1) +$$
$$+2\cdot 0{,}08\cdot 6\pi\cdot 3{,}39 = 10 \text{ N}.$$

As the spring stiffness increases, the oscillation frequency increases and the deflection amplitude decreases. As the angular velocity increases, the pressure on the coupling wall increases significantly. Thus, the spring and rotation parameters play a role in setting up the system.

Analysis of the results. Numerical simulation of the dynamics of the pad movement in an elastic lever clutch made it possible to obtain quantitative estimates of the deviation of the coordinate, velocity and acceleration of the centrifugal pad movement and pressure on the wall of the clutch cutout at various time values. The results obtained indicate the regular nature of the mechanism's behavior and confirm the possibility of its use as a mechanical regulator for chisel feed when drilling exploration wells.

The results of numerical integration have shown that the motion of the centrifugal pad is oscillatory in nature with a gradual attenuation of vibrations and transition to a steady state. At the initial stage, significant amplitudes of deviations and velocities are observed, which is due to the inertia of the system and the impact of the initial disturbance. In steady state, the deflection angle stabilizes, which corresponds to a stable load on the chisel (Akhmetov et al., 2008a).

The pressure developed by the pad on the inner surface of the coupling depends on:

– the radius of deflection of the lever;

– angular rotation speed of the coupling;

– pad weights.

A survey of the sources showed that under conditions corresponding to real drilling conditions, the pressure reaches values up to 90-100 kPa, which is sufficient to effectively activate the control mechanism for feeding the bit. This confirms the possibility of using the coupling as a sensing element in the axial load control system (Medetov et al., 2008).

The calculations performed with varying parameters showed the following effects:

– Increasing the spring stiffness leads to a faster return of the centrifugal pad to its original position, reduces the amplitude of vibrations and reduces the deflection radius, thereby reducing the sensitivity of the clutch to changes in rotation speed.

– An increase in angular velocity causes a significant increase in centrifugal force, accelerates the movement of the centrifugal pad and increases the pressure on the wall, which contributes to a more active effect on the feed mechanism.

– Changing the mass of the centrifugal pad affects the inertial component, as well as the amount of centrifugal force and torque, which can be used to adjust the sensitivity of the coupling.

Practical conclusions. The analysis confirms that the dynamic model accurately reflects the physical essence of the processes in the coupling. The obtained dependences allow:

– To determine the optimal parameters of the coupling design;

– Predict the system's response to changing drilling conditions;

– Adjust the column feed modes to ensure a given axial load on the chisel.

The mechanical coupling with centrifugal pads demonstrates high reliability and sensitivity, which makes it particularly effective in environments where the use of electronic equipment is limited (Akhmetov et al., 2008b).

Conclusions. In this paper, the dynamics of the operation of an elastic lever clutch with centrifugal pads used in the drive of the bit feed regulator during drilling of exploration wells is investigated. The main attention is paid to the mathematical modeling of the pad movement, the numerical integration of equations and the analysis of the resulting loads on the coupling elements.

Based on the performed research, the following conclusions were obtained (Akhmetov et al., 2008b):

1. A second-order nonlinear differential equation has been compiled describing the motion of the shoe under the action of centrifugal force, spring elasticity and medium resistance. The equation takes into account the physical parameters of the design and can be used to analyze different operating modes of the coupling.

2. Numerical integration made it possible to determine the coordinate, speed and acceleration of movement and pressure on the wall of the coupling.

3. The pressure on the wall of the coupling cutout created by the block depends on the angular velocity of rotation, mass and position of the lever. At typical pressure parameters, they reach 70-100 kPa, which confirms the operability of the mechanism as a supply regulator.

4. An analysis of the system parameters showed that the spring stiffness, pad weight, and rotation speed critically affect the sensitivity and stability of the clutch. These parameters can be used to fine-tune the device to specific drilling conditions.

5. The results obtained are of practical importance for drilling equipment designers and drilling engineers, as they make it possible to optimize the design of

the mechanical bit feed regulator and increase drilling efficiency by automatically maintaining the required axial load.

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