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DYNAMIC SCHEME AND MATHEMATICAL MODEL OF A MULTI-FREQUENCY VIBRATING SIEVE FOR DRILLING MUD CLEANING

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Abstract. Improving the technique and technology of cleaning drilling muds from drilled rock, increasing the speed of well drilling and improving the quality of drilling mud is an important scientific and applied problem that is of great importance for the oil and gas industry. A calculation dynamic scheme of a vibrating multi-frequency sieve for cleaning drilling muds with a limited source of excitation was developed. The vibrating sieve is a two-mass system connected to each other and to a fixed base by means of one-sided bonds of elastic and damping elements. It is the first dynamic scheme which allows to model a vibrating multi-frequency sieve as a multi-mass essentially nonlinear dynamic system with a limited source of excitation, taking into account retaining bonds and elastic limiters of a certain stiffness and viscosity, as well as gaps between the casing and the limiters. The system is characterized by two related coordinates: rotary - the angle of rotation of the rotor of the vibrator, and oscillatory - the displacement of the masses of the vibrating sieve along the x axis. Based on the dynamic scheme, a mathematical model of a vibrating multi-frequency sieve for cleaning drilling mud was first developed, which allows modeling the dynamics of the sieve as a multi-mass essentially nonlinear dynamic system. The system of equations of the model describes the movement of the masses of the system and takes into account the movement of the casing, the movement of the impactor, the forces in the retaining bonds of the casing, the forces in the retaining bonds of the impactor, the forces in the elastic limiters, the angle of rotation of the debalance, the torque on the debalance shaft, the moment of resistance to rotation of friction forces in the bearings. A computational algorithm for integrating over time the equations of motion that describe the dynamics of a multi-frequency vibrating sieve is proposed, which is based on the use of three-layer difference schemes with weights. The use of the computational algorithm for integrating the equations of motion of the analyzed dynamic system allows us to obtain time series describing the movement of concentrated masses of the dynamic system at discrete moments of time.

Keywords: vibrating multi-frequency sieve, drilling muds, cleaning, dynamic scheme, mathematical model, computational algorithm.

1. Introduction

Increasing the level of hydrocarbon production, primarily oil and gas, requires an increase in the pace of preparation of new wells. When drilling wells, the drilling process itself and the removal of the drilled rock from the well are ensured by drilling mud, which is supplied to the well under pressure. To perform these functions, the drilling mud must have certain stable physicochemical properties, in particular, density with a limited number of solid particles suspended in it. For this, the drilling mud that comes out of the well is cleaned from solid rock particles. The number of solid particles remaining in the fluid after cleaning is one of the factors limiting the permissible drilling speed. Therefore, the drilling mud cleaning and the residual concentration of solid particles in the cleaned drilling mud limit the well drilling speed. In this regard, improving the technique and technology of cleaning drilling muds from drilled rock, increasing the speed of well drilling, and improving the quality of drilling mud is an important scientific and applied problem that is of great importance for the oil and gas industry [1–8].

However, the task of increasing the efficiency, reliability and productivity of such equipment and technologies requires the use of new non-standard approaches. The authors propose the use of drilling mud cleaning technology on a vibrating multi-frequency sieve. The implementation of multi-frequency oscillations and a multiple increase in the acceleration of sieve oscillations, compared to typical vibrating sieves for cleaning drilling muds, will ensure an increase of the productivity and efficiency

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of drilling muds cleaning on vibrating multi-frequency sieves compared to traditional vibrating sieves with mono-frequency excitation [9, 10]. This will allow to increase the permissible drilling speed, which is limited by the degree of cleaning drilling muds from rock particles, and will contribute to an increase in the technical and economic indicators of the drilling process. Untill now, a mathematical model of a vibrating multi-frequency sieve has not been developed as a substantially nonlinear dynamic system, the regularities of changes in the power, energy and operating parameters of a vibrating multi-frequency sieve have not been established, and recommendations for cleaning drilling muds on a vibrating multi-frequency sieve have not been developed.

Therefore, the development of a calculation dynamic scheme, a mathematical model of a vibrating multi-frequency sieve for cleaning drilling muds and a computational algorithm for its realization for further study of the process and establishment of regularities of changes in the power, energy and operating parameters of a vibrating multi-frequency sieve and justification of its rational parameters is an urgent scientific task that is of significant importance for the oil and gas production industry of the country.

2. Methods

Fig. 1 shows the calculated dynamic diagram of a vibrating multi-frequency sieve with a limited excitation source [11–16]. The vibrating sieve is a two-mass system connected to each other and to a fixed base by means of one-sided bonds of elastic and damping elements. The system consists of a casing with a mass m_1 and the working body (impactor) with mass m_2. The casing is installed on a fixed base using retaining bonds with stiffness c_{p10} and viscosity b_{p10}. The impactor is attached to the casing using retaining bonds with stiffness c_{p21} and viscosity b_{p21} and is equipped at the top and bottom with elastic limiters with stiffnesses c_{r12} and c_{r21} and viscosity b_{r12} and b_{r21} respectively. To relief the start-up of the system, gaps are arranged between the casing and the limiters δ_{12} and δ_{21}. A debalanced vibrator is installed on the sieve casing, which is driven by an asynchronous electric motor and rotates in a horizontal plane. The mass of the debalances in the vibrator is m_0, eccentricity – r, moment of inertia – J, nominal power – N_n. In the process of rotation of debalanced masses, a centrifugal force of inertia arises, which excites small forced oscillations of the masses of the vibrating sieve. Oscillations of the masses of the vibrating sieve are considered only along the x axis. Therefore, the system is characterized by two related coordinates: the rotary - the angle of rotation of the rotor of the vibrator φ, and the oscillation - the displacement of the masses of the vibrating sieve along the x axis.

The presented dynamic scheme is the first that allows to model a vibrating multi-frequency sieve for cleaning drilling mud as a multi-mass, essentially nonlinear dynamic system with a limited excitation source, taking into account the retaining bonds and elastic limiters of a certain stiffness and viscosity, as well as the gaps between the casing and the limiters.

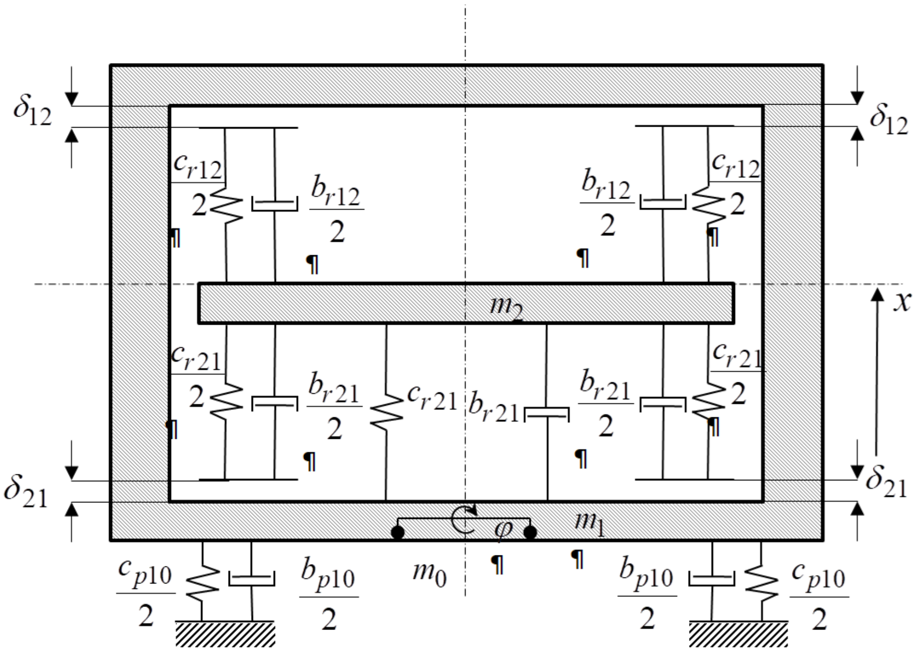

Figure 1 – Calculation diagram of a vibrating sieve with a limited excitation source

3. Theoretical part

The system of equations describing the motion of the system shown in Fig. 1 has the form:

$$\begin{cases} (m_1 + m_0)\ddot{x}_1 + P_1 - P_2 - P_{01} + P_{02} = m_0 r\ddot{\varphi}\sin\varphi + m_0 r\dot{\varphi}^2\cos\varphi; \\ m_2\ddot{x}_2 + P_2 + P_{01} - P_{02} = 0; \\ J\ddot{\varphi} = m_0 r\ddot{x}\sin\varphi + L(\dot{\varphi}) - R(\dot{\varphi}) + m_0 g r\sin\varphi, \end{cases} \tag{1}$$

where x_1 – displacement of the casing, m; x_2 – displacement of the impactor, m; P_1 – force in the casing retaining bonds, N; P_2 – force in the impactor retaining bonds, N; P_{01}, P_{02} – force in the elastic limiters, N; φ – angle of rotation of the debalance, deg; L – torque on the debalance shaft, N m; R – moment of resistance to rotation of friction forces in the bearings, N m; g – acceleration of free fall, m/s ^{2}.

The forces in two-way elastic bonds are calculated by the formulas:

$$P_1 = c_{p10}x_1 + b_{p10}\dot{x}_1;\; P_2 = c_{p21}(x_2 - x_1) + b_{p21}(\dot{x}_2 - \dot{x}_1).$$

The forces in one-way bonds are calculated using the formulas:

$$P_{01} = (c_{r12}\delta_{12} + b_{r12}\dot{\delta}_{12})H(-\delta_{12});\; P_{02} = (c_{r21}\delta_{21} + b_{r21}\dot{\delta}_{21})H(-\delta_{21}),$$

where $H(-\delta_j)$ – Heaviside functions, which are defined as follows:

$$H(-\delta_{12}) = \begin{cases} 1, & \delta_{12} > 0 \\ 0, & \delta_{12} \le 0 \end{cases}, \; H(-\delta_{21}) = \begin{cases} 1, & \delta_{21} > 0 \\ 0, & \delta_{21} \le 0 \end{cases}.$$

Current gaps (tensions) in one-way bonds:

$$\delta_{12}(t) = x_2(t) - x_1(t) + \delta_{12}; \; \delta_{21}(t) = x_1(t) - x_2(t) + \delta_{21}.$$

The torque on the debalance shaft of the vibration exciter is determined by the formula:

$$L = \eta u \widetilde{M}, \tag{2}$$

where η – efficiency of the drive; u – gear ratio of the drive; $\widetilde{M}$ – torque on the engine shaft, N m.

In the vibrating multi-frequency sieve for cleaning drilling muds, three-phase asynchronous electric motors with a squirrel-cage rotor are used as an energy source. For such motors, the mechanical characteristic (dependence of the motor torque on slip) is determined by the Kloss formula [11–16]:

$$\widetilde{M} = \frac{2M_{kr}}{s/s_{kr} + s_{kr}/s}, \tag{3}$$

where M_{kr} – critical engine torque, N m; s_{kr} – critical engine slip, %; s – current slip, rpm.

The critical torque of an asynchronous electric motor is determined by the formula:

$$M_{kr} = \zeta M_n, \tag{4}$$

where ζ – the overload capacity of the engine, which characterizes its ability to withstand short-term loads; M_n – the nominal torque of the engine, N m.

The nominal torque of an asynchronous motor is determined by the formula:

$$M_n = \frac{1000 N_n}{\omega_n}, \tag{5}$$

where N_n – nominal engine power, kW; ω_n – nominal engine angular speed, rpm.

The critical slip of an asynchronous electric motor is determined by the dependence:

$$s_{kr} = s_n(\zeta + \sqrt{\zeta^2 - 1}), \tag{6}$$

where s_n – the nominal slip, determined by the formula:

$$s_n = \frac{\omega_c - \omega_n}{\omega_c}, \tag{7}$$

where ω_c – synchronous angular velocity of the rotor is calculated by the formula:

$$\omega_c = \frac{2\pi f_c}{p}, \tag{8}$$

where f_c – current frequency in the power supply network, Hz; p – number of pole pairs of an asynchronous motor, units.

The current slip value is determined by the formula:

$$s = \frac{\omega_c - \omega}{\omega_c}, \tag{9}$$

where ω – the current value of the angular velocity, which is calculated by the formula:

$$\omega = u\dot{\varphi}. \tag{10}$$

The moment of resistance to rotation from friction forces in bearings, which is determined by the conditional coefficient of rolling friction, the centrifugal force of debalance during its rotation and the diameter of the debalance shaft are determined by well-known expressions [11–16].

To solve the equations of motion of the system (1), it is necessary to supplement the initial conditions. We will assume that at the initial time ($t = 0$) the system was at rest, i.e.

$$\begin{cases} x_1(0) = 0,\ \dot{x}_1(0) = 0; \\ x_2(0) = 0,\ \dot{x}_2(0) = 0; \\ \varphi(0) = 0,\ \dot{\varphi}(0) = 0. \end{cases} \tag{11}$$

Since it is difficult to obtain an analytical solution to equations (1)–(11), it is advisable to search for a solution by numerical integration. The computational algorithm used for this can be based on three-layer schemes with weights.

Let us divide the time axis into equal segments $[t^k, t^{k+1}]$, $k = 1, 2, \ldots$ so that the period of oscillations T has an integer number of segments K. Let us denote the length of these segments by h. Further, we will understand x_n^k as the displacement of the mass m_n, $n=\overline{1,N}$, at the time t^k, i.e. $x_n^k = x_n(t^k)$. Similarly, we will understand $x_0^k = x_0(t^k)$ as the displacements of the moving base. The three-layer difference scheme with weights for the equations of motion (1) has the form:

$$M\frac{X^{k+1}-2X^k+X^{k-1}}{h^2}+B\frac{X^{k+1}-X^{k-1}}{2h}+CX^{k+\theta}+\widetilde{P}^{k+\theta}+R^{k+\theta}=Q^{k+\theta}, \quad (12)$$

where M – diagonal mass matrix of the dynamical system

$$M = diag\{\, m_1, m_2, \ldots, m_N \};\quad (13)$$

$B=\left\|B_{ij}\right\|$ – damping matrix of the dynamic system

$$B_{ij}=\begin{cases}\sum\limits_{n\in J_{ip}} b_{pin}+\sum\limits_{n\in J_{pi}} b_{pni}, & i=j\\ -b_{pij}, \quad i\neq j, \quad (i,j)\in J_p\,;\, i,j=\overline{1,N}, & \\ 0, \quad i\neq j, \quad (i,j)\notin J_p & \end{cases}\quad (14)$$

$C=\left\|C_{ij}\right\|$ – stiffness matrix of the dynamic system

$$C_{ij}=\begin{cases}\sum\limits_{n\in J_{ip}} c_{pin}+\sum\limits_{n\in J_{pi}} c_{pni}, & i=j\\ -c_{pij}, \quad i\neq j, \quad (i,j)\in J_p\,;\, i,j=\overline{1,N}, & \\ 0, \quad i\neq j, \quad (i,j)\notin J_p & \end{cases}\quad (15)$$

$X^k=\left\{x_1^k, x_2^k, \ldots, x_N^k\right\}^T$ – vector of mass displacements of the dynamic system in the k time layer;

$$\widetilde{P}^{k+\theta}=\theta_1\widetilde{P}^{k+1}+\theta_2\widetilde{P}^k+\theta_3\widetilde{P}^{k-1};\quad (16)$$

$$\widetilde{P}^k=\left\{\widetilde{P}_1^k, \widetilde{P}_2^k, \ldots, \widetilde{P}_N^k\right\}^T;\quad (17)$$

$$\widetilde{P}_n^k=\sum_{i\in J_{np}} d_{pni}\left|x_n^k-x_i^k\right|^{\alpha_{pni}} sign(x_n^k-x_i^k)-$$

$$-\sum_{i\in J_{pn}} d_{pin}\left|x_i^k - x_n^k\right|^{\alpha_{pin}} sign(x_i^k - x_n^k); \quad (18)$$

$$R^{k+\theta} = \theta_1 R^{k+1} + \theta_2 R^k + \theta_3 R^{k-1}; \quad (19)$$

$$R^k = \left\{R_1^k, R_2^k, \ldots, R_N^k\right\}^T; \quad (20)$$

$$R_n^k = \sum_{i\in J_{np}}\left[c_{rni}(x_n^k - x_i^k + \delta_{ni}) + d_{rni}\left|x_n^k - x_i^k + \delta_{ni}\right|^{\alpha_{rni}} \times\right.$$
$$\left.\times sign\,(x_n^k - x_i^k + \delta_{ni}) + b_{rni}(\dot{x}_n^k - \dot{x}_i^k)\right] H(x_n^k - x_i^k - \delta_{ni}) -$$
$$-\sum_{i\in J_{pn}}\left[c_{rin}(x_i^k - x_n^k + \delta_{in}) + d_{rin}\left|x_i^k - x_n^k + \delta_{in}\right|^{\alpha_{rin}} \times\right.$$
$$\left.\times sign\,(x_i^k - x_m^k + \delta_{in}) + b_{rin}(\dot{x}_i^k - \dot{x}_n^k)\right] H(x_i^k - x_n^k - \delta_{in}); \quad (21)$$

$$Q^{k+\theta} = \theta_1 Q^{k+1} + \theta_2 Q^k + \theta_3 Q^{k-1}; \quad (22)$$

$$Q^k = \left\{q_1^k, q_2^k, \ldots, q_N^k\right\}^T; \quad (23)$$

$$q_n^k = \begin{cases} q_{sn} + q_{\omega n}\sin\omega t^k,\ (n,0)\notin J_r, (0,n)\notin J_r; \\ q_{sn} + q_{\omega n}\sin\omega t^k + b_{n0}A\omega\sin\omega t^k + c_{n0}A\sin\omega t^k, (n,0)\in J_r; \\ q_{sn} + q_{\omega n}\sin\omega t^k + b_{0n}A\omega\sin\omega t^k + c_{0n}A\sin\omega t^k, (0,n)\in J_r; \end{cases}$$
$$n = \overline{1,N}, \quad (24)$$

where θ_i – weight coefficients, $i = \overline{1,3}$:

$$\theta_1 + \theta_2 + \theta_3 = 1. \quad (25)$$

To calculate the components $\widetilde{P}^{k+\theta}$, $R^{k+\theta}$ and $Q^{k+\theta}$ included in (12), one can also use alternative representations:

$$\widetilde{P}^{k+\theta} = \left\{\widetilde{P}_1^{k+\theta}, \widetilde{P}_2^{k+\theta}, \ldots, \widetilde{P}_N^{k+\theta}\right\}^T; \quad (26)$$

$$\widetilde{P}_n^{k+\theta} = \sum_{i\in J_{np}} d_{pni}\left|x_n^{k+\theta} - x_i^{k+\theta}\right|^{\alpha_{pni}} sign(x_n^{k+\theta} - x_i^{k+\theta}) -$$

$$-\sum_{i\in J_{pn}} d_{pin}\left|x_i^{k+\theta}-x_n^{k+\theta}\right|^{\alpha_{pin}} sign(x_i^{k+\theta}-x_n^{k+\theta})\,; \qquad \mathbf{(27)}$$

$$R^{k+\theta}=\left\{R_1^{k+\theta}, R_2^{k+\theta},\dots, R_N^{k+\theta}\right\}^T; \qquad (28)$$

$$R_n^{k+\theta}=\sum_{i\in J_{np}}\Big\lfloor c_{rni}(x_n^{k+\theta}-x_i^{k+\theta}+\delta_{ni})+$$
$$+d_{rni}\left|x_n^{k+\theta}-x_i^{k+\theta}+\delta_{ni}\right|^{\alpha_{rni}} sign\,(x_n^{k+\theta}-x_i^{k+\theta}+\delta_{ni})+$$
$$+b_{rni}(\dot{x}_n^{k+\theta}-\dot{x}_i^{k+\theta})\Big\rfloor H(x_n^{k+\theta}-x_i^{k+\theta}-\delta_{ni})-$$
$$-\sum_{i\in J_{pn}}\Big\lfloor c_{rin}(x_i^{k+\theta}-x_n^{k+\theta}+\delta_{in})+$$
$$+d_{rin}\left|x_i^{k+\theta}-x_n^{k+\theta}+\delta_{in}\right|^{\alpha_{rin}} sign\,(x_i^{k+\theta}-x_m^{k+\theta}+\delta_{in})+$$
$$+b_{rin}(\dot{x}_i^{k+\theta}-\dot{x}_n^{k+\theta})\Big\rfloor H(x_i^{k+\theta}-x_n^{k+\theta}-\delta_{in}); \qquad (29)$$

$$Q^{k+\theta}=\left\{q_1^{k+\theta}, q_2^{k+\theta},\dots, q_N^{k+\theta}\right\}^T; \qquad (30)$$

where

$$q_n^{k+\theta}=\begin{cases} q_{sn}+q_{\omega n}\sin\omega t^{k+\theta}, (n,0)\notin J_r, (0,n)\notin J_r; \\ q_{sn}+q_{\omega n}\sin\omega t^{k+\theta}+b_{n0}A\omega\sin\omega t^{k+\theta}+c_{n0}A\sin\omega t^{k+\theta}, (n,0)\in J_r; \\ q_{sn}+q_{\omega n}\sin\omega t^{k+\theta}+b_{0n}A\omega\sin\omega t^{k+\theta}+c_{0n}A\sin\omega t^{k+\theta}, (0,n)\in J_r; \end{cases}$$
$$n=\overline{1,N} \qquad (31)$$

$$x_n^{k+\theta}=\theta_1 x_n^{k+1}+\theta_2 x_n^k+\theta_3 x_n^{k-1},\ n=\overline{1,N}; \qquad (32)$$

$$t^{k+\theta}=\theta_1 t^{k+1}+\theta_2 t^k+\theta_3 t^{k-1}. \qquad (33)$$

When using a three-layer difference scheme (12), there is a problem with starting the step process, which is related to the fact that the initial conditions (initial position and initial velocity) are set on one time layer. As a rule, two-layer difference schemes are used for calculations in the first step. This approach complicates the computational algorithms, and there is a problem of matching the accuracy and time step of the three-layer and two-layer schemes. For this problem, it is appropriate to use another approach, according to which the position of the dynamic system is given on the time layer preceding the initial moment of time $t=0$. We will assume that at time $t=-h$ the analyzed dynamic system is also in a state of rest, i.e. we will assume

$$X^0 = X^{-1} = 0. \quad (34)$$

The main issue that arises in the practical use of the above difference scheme is the choice of weight coefficients θ_i, $i = \overline{1,3}$ and the time integration step h, which ensure the given accuracy and stability of the computational algorithm. It is quite difficult to perform a rigorous mathematical study of the stability and accuracy of the difference scheme (12) due to the presence of nonlinear terms. It is known that when solving linear problems without damping, a three-layer difference scheme with weights will be stable according to the initial data if the conditions are met

$$\theta_1 \ge \theta_3,\ \theta_1 + \theta_3 \ge 1/2. \quad (35)$$

Therefore, when solving the nonlinear problem under consideration, the values of the weight coefficients were taken as follows

$$\theta_1 = \theta_3 = 1/4,\ \theta_2 = 1/2. \quad (36)$$

When using the implicit difference scheme ($\theta_1 > 0$), relations (12) represent a system of nonlinear equations with respect to the X^{k+1} mass displacement vector of the analyzed dynamic system on the time layer $(k+1)$

$$\left(\frac{M}{h^2} + \frac{B}{2h} + \theta_1 C\right) X^{k+1}_{(s+1)} = \left(\frac{2M}{h^2} - \theta_2 C\right) X^k + \\ + \left(-\frac{M}{h^2} + \frac{B}{2h} - \theta_3 C\right) X^{k-1} - \widetilde{P}^{k+\theta}_{(s)} - R^{k+\theta}_{(s)} + Q^{k+\theta}, \quad (37)$$

where s is the iteration number.

The iterative process continues until the stopping condition is met

$$\left\| X^{k+1}_{(s+1)} - X^{k+1}_{(s)} \right\| < \varepsilon \left\| X^{k+1}_{(s+1)} \right\|, \quad (38)$$

where ε is a parameter characterizing the convergence accuracy of the iterative process.

It is easy to see that if the iterative process (37) converges, the limit of the sequence $\left\{X^{k+1}_{(s)}\right\}$ is a solution to the system of nonlinear algebraic equations (12). As an initial approximation for the iterative process (37) we can choose

$$X^{k+1}_{(0)} = X^k. \quad (39)$$

The application of the above computational algorithm for integrating the equations of motion of the analyzed dynamic system allows us to obtain time series $\{X^k\}$ describing the movement of concentrated masses of the dynamic system at discrete moments of time t^k, which are usually taken at equal intervals of time h, called the discretization period.

It is for the first time when mathematical model of a vibrating multi-frequency sieve for cleaning drilling mud was developed, which allows modeling the dynamics of the sieve as a multi-mass, essentially nonlinear dynamic system. The system of equations describes the motion of the masses of the system and takes into account the movement of the casing, the movement of the impactor, the forces in the casing retaining bonds, the forces in the impactor retaining bonds, the forces in the elastic limiters, the angle of rotation of the debalance, the torque on the debalance shaft, the moment of resistance to rotation of friction forces in the bearings, etc.

4. Conclusions

1. A calculation dynamic scheme of a vibrating multi-frequency sieve for cleaning drilling muds with a limited source of excitation was developed. The vibrating sieve is a two-mass system connected to each other and to a fixed base by means of one-sided elastic and damping elements. The system consists of a casing and a working body (impactor). The casing is installed on a fixed base by means of retaining bonds. The impactor is attached to the casing by means of retaining bonds and is equipped with elastic limiters at the top and bottom. To facilitate the start-up of the system, gaps are arranged between the casing and the limiters. A debalanced vibration exciter is installed on the sieve casing, which is driven into rotation by an asynchronous electric motor and rotates in a horizontal plane. In the process of rotation of debalanced masses, a centrifugal force of inertia arises, which excites small forced oscillations of the masses of the vibrating sieve. The system is characterized by two related coordinates: the rotational coordinate - the angle of rotation of the rotor of the vibration exciter, and the oscillatory coordinate - the displacement of the masses of the vibrating sieve along the axis x.

2. A mathematical model of a multi-frequency vibrating sieve for cleaning drilling muds was developed. The motion of the system is described by a system of equations that take into account the movement of the casing, the movement of the impactor, the forces in the casing retaining bonds, the forces in the ipmactor retaining bomds, the forces in the elastic limiters, the angle of rotation of the debalance, the torque on the debalance shaft, the moment of resistance to rotation of friction forces in the bearings, etc.

3. A computational algorithm for integrating over time the equations of motion describing the dynamics of a multi-frequency vibrating sieve is proposed which is based on the use of three-layer difference schemes with weights. The use of a computational algorithm for integrating the equations of motion of the analyzed dynamic system allows us to obtain time series describing the movement of concentrated masses of the dynamic system at discrete moments of time.

4. The calculation dynamic scheme, the mathematical model of the vibrating multi-frequency sieve for cleaning drilling muds and the algorithm for its implementation will be used for further research into the process and establishing the regularities of changes in the power, energy and operating parameters of the vibrating multi-frequency sieve and substantiating its rational parameters, which is an urgent scientific task that is of significant importance for the oil and gas production industry of the country.

Conflict of interest

Authors state no conflict of interest.

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ДИНАМІЧНА СХЕМА ТА МАТЕМАТИЧНА МОДЕЛЬ ВІБРАЦІЙНОГО ПОЛІЧАСТОТНОГО СИТА ДЛЯ ОЧИЩЕННЯ БУРОВИХ РОЗЧИНІВ

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Анотація. Удосконалення техніки та технології очищення бурових розчинів від вибуреної породи, збільшення швидкості буріння свердловин та поліпшення якості бурового розчину є важливою науково-прикладною проблемою, що має важливе значення для нафто- та газодобувної галузі. Розроблено розрахункову динамічну схему вібраційного полічастотного сита для очищення бурових розчинів з обмеженим джерелом збудження. Вібраційне сито представляє собою двомасну систему, пов'язаних між собою та нерухомою основою за допомогою односторонніх зв'язків пружних та демпфуючих елементів. Динамічна схема вперше дозволяє моделювати вібраційне полічастотне сито, як багатомасну суттєво нелинійну динамічну систему з обмеженим джерелом збудження з урахуванням утримуючих зв'язків і пружних обмежувачів певної жорсткості та в'язкості, а також зазорів між коробом і обмежувачами. Система характеризується двома пов'язаними координатами: поворотною – кутом повороту ротора вібрprinciple збудника і коливальною - зміщенням мас вібросита по осі x. На основі динамічної схеми вперше розроблено математичну модель вібраційного полічастотного сита для очищення бурових розчині, яка дозволяє моделювати динаміку сита, як багатомасної суттєво нелінійної динамічної системи. Система рівнянь моделі описує рух мас системи та враховує переміщення короба, переміщення ударника, зусилля в утримуючих зв'язках короба, зусилля в утримуючих зв'язках ударника, зусилля в пружних обмежувачах, кут повороту дебалансу, крутний момент на валу дебалансів, момент опору обертанню сил тертя в підшипниках. Запропоновано обчислювальний алгоритм інтегрування за часом рівнянь руху, що описують динаміку полічастотного вібросита, який засновано на використанні тришарових різницевих схем з вагами. Застосування обчислювального алгоритму інтегрування рівнянь руху аналізованої динамічної системи дозволяє отримати часові ряди, що описують переміщення зосереджених мас динамічної системи в дискретні моменти часу.

Ключові слова: вібраційне полічастоне сито, бурові розчини, очищення, динамічна схема, математична модель, обчислювальний алгоритм.