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IDENTIFICATION OF PARAMETERS AND RESEARCH OF THE MATHEMATICAL MODEL OF A VIBRATING MULTI-FREQUENCY SIEVE FOR CLEANING DRILLING MUD

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Abstract. In order to study the process and establish the regularities of changes in the power, energy and regime parameters of a vibrating multi-frequency sieve and to substantiate its rational parameters, the parameters of the mathematical model and the method of studying the influence of the power of the vibration exciter electric motor on the vibrating multi-frequency sieve for cleaning drilling muds entering the stationary vibration modes were identified. The influence of the input parameters of the mathematical model of a sieve with limited power of the vibration exciter on the research results was assessed and their identification was performed. For the research, the methods of studying the mathematical model were selected, which most closely correspond to the dynamic processes of entering and establishing stationary vibroimpact oscillation modes of a multi-frequency sieve for effective cleaning of drilling muds. The method of research of the mathematical model of a vibrating multi-frequency sieve for establishing the regularities of the influence of the power of the electric motor of the vibration exciter on the sieve entering the stationary oscillation modes, which most corresponds to the dynamic processes of entering and establishing stationary vibroimpact oscillation modes, is the method of sequential start of the model with selected parameters of the electric motor. The research method of continuation by parameter of the mathematical model of the sieve should be used to study the regularities of the influence of the change in the mass of the impactor, modeling the change in the attached mass of the technological load or the properties of elastic bonds under the influence of temperature heating or aging on the modes and parameters of oscillations of a vibrating multi-frequency sieve. It is shown that with the method of continuation by frequency in condiotion of the sieve operating parameters and changing accelerations of the sieve mass oscillations in the range of 1–157 rad/s, vibroimpact oscillations are realized in the sieve at a power of N=1.315 kW in the same way as with the method of continuation by power in the range of its change of 2.7–4.2 kW. Therefore, when system starts by frequency and drive power at N=1.315 kW, vibrimpact oscillation modes are implemented in the sieve. By comparing the obtained results of research of a single-mass model with elastic vibration limiters and limited power of the vibration exciter with the results of research of such a model with an ideal source of oscillations, we were able to confirm the correctness of the assumptions made when choosing the model of an asynchronous electric motor.

Keywords: identification of parameters, mathematical model, vibrating multi-frequency sieve, cleaning of drilling muds, regularities, vibration modes.

1. Introduction

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].

The authors propose to use a technology of drilling mud cleaning by the 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 increased productivity and efficiency of drilling mud cleaning on vibrating multi-frequency sieves compared to traditional vibrating sieves with single-frequency excitation [9, 10]. This will allow increasing the permissible drilling speed, which is limited by the degree of cleaning drilling muds from rock particles, and will contribute to increasing the technical and economic indicators of the drilling process.

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The main directions of increasing the efficiency of vibration technologies for processing mineral raw materials are the selection and optimization of dynamic parameters of the load of vibration equipment and technological raw materials on the working body, related both to energy-force interactions and to the mechanical and structural characteristics of the raw materials. For polydisperse systems, which are the majority of technological materials in the processing of mineral raw materials, the optimal modes of vibration influence lie in the area of resonant multi-frequency excitation and require deep and independent regulation of the vibration excitation parameters taking into account changes in the values and characteristics of the technological load [11–23]. A dynamic scheme and a mathematical model of a vibrating multi-frequency sieve for cleaning drilling muds [24], methods of the analysis of forced oscillations of a vibrating multi-frequency sieve for cleaning drilling muds by the method of computational experiment [25] have been developed. For further study of the process and establishment of regularities of changes in power, energy and regime parameters of the vibrating multi-frequency sieve and substantiation of its rational parameters, it is necessary to identify the parameters of the mathematical model of the vibrating multi-frequency sieve for cleaning drilling muds.

Therefore, identification of the parameters of the mathematical model of a vibrating multi-frequency sieve for cleaning drilling muds 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

The initial data of the mathematical model of a vibrating multi-frequency sieve [24] include operating parameters of the sieve, such as the mass of its elements, the parameters of two-way and one-way bonds, and the parameters of vibration exciters, as well as the parameters on which the ranges of the performed studies for a given operating parameter and the accuracy of the obtained calculation results depend. These parameters are: the number of calculations, the number of steps per period, and the number of periods per time.

The number of calculations enables performing one calculation with fixed parameter values or several consecutive system calculations when specifying the range of change of the researched sieve parameter. With fixed parameters and a single calculation, the number of calculations is set to 1. When changing the parameter in the specified range of studies, the number of calculations sets the step with which the parameter will change. For example, when specifying the range of change of the external load frequency from 1 rad/s to 156 rad/s with a step of 1 rad/s, the number of calculations is 156. With a step of 2 rad/s, it is, respectively, 78. In this case, the sign of using the method of continuation by parameter is 1. With a single calculation - 0 (the method of continuation by parameter is disabled).

The number of steps per period determines the integration step or the number of intervals into which each period of the system excitation is divided. The parameter can take any positive integer value. The accuracy of the obtained calculation results depends on the value of this parameter and calculation time. There is a limiting value of the parameter from which the accuracy of calculations does not change with an increase in the steps in the period. Based on the experimental calculations on a model of a multi-frequency sieve with an ideal excitation source, the minimum limiting value of this parameter is 1000 steps. If, upon completion of the calculations, all the results are zero, then this means that an insufficient number of steps has been selected and their number should be increased, usually in steps of 1000. As a rule, the limiting value of the parameter does not exceed 3000. To confirm the absence of the parameter's influence on the accuracy of the calculation results, after calculations with some values, the calculation results should be compared with the previous calculation results. If the calculation results coincide, this indicates the correctness of the selected parameter.

Number of periods in time. This parameter determines how many periods of system excitation will be calculated for each of the selected parameter values. Thus, for each given value of the system parameters, *NT* periods will be calculated. Therefore, the accuracy and calculation time depend on this parameter. The criterion for the correctness of the parameter selection is the system's entering the established mode after *NT* periods of forced oscillations. If after *NT* periods, the system enteres the set mode, then the parameter has been selected correctly. The criterion for selecting a parameter is the coincidence of the calculation results in two or more of the last calculation periods with the specified system parameters.

3. Theoretical part

Fig. 1 shows the dependence of the accelerations of sieve mass oscillations at the basic parameters given in Table 1 and the number of steps in the period *NH*=10 for the last 10 excitation periods out of 1000 calculated (*NT*=1000). The physical content of the parameters presented in Table 1 is given in [24].

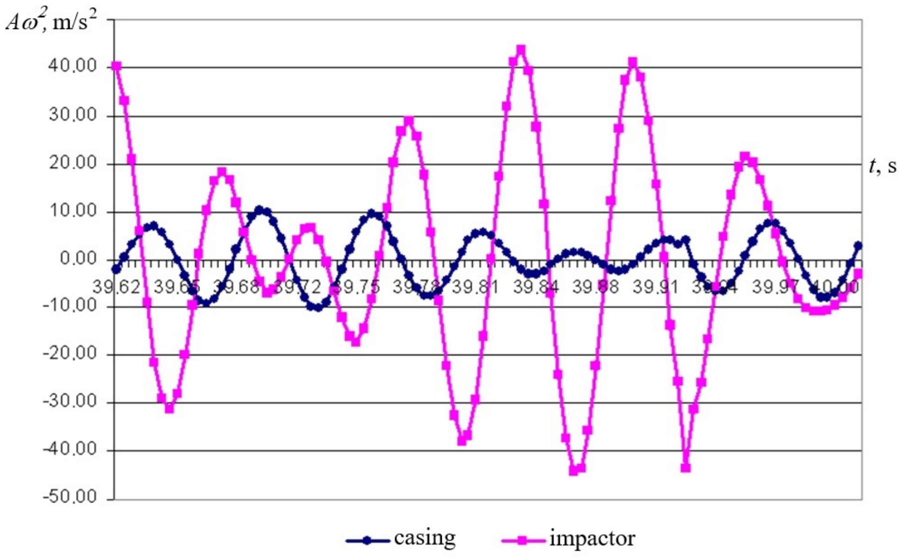

Figure 1 – Dependence of the accelerations of sieve mass oscillations at *NH*=10, *NT*=1000 and basic sieve parameters for the last 10 oscillation periods

Table 1 – Basic sieve parameters

Parameter, units of measurement	Symbols	Value
Casing weight, kg	m_1	1600
Impactor weight, kg	m_2	380
Stiffness of two-way elastic bonds between the box and the fixed base, N/m	c_{p01}	480000
Viscosity of elastic bonds c_{p01}, kg/s	b_{p01}	1000
Stiffness of two-way elastic bonds between the box and the ipmactor, N/m	c_{p02}	4000000
Viscosity of elastic bonds c_{p02}, kg/s	b_{p02}	1000
Stiffness of the upper one-way elastic bond between the box and the impactor, kN/m	c_{r01}	120000
Viscosity coefficient of one-way elastic bonds c_{r01}, kg/s	b_{r01}	2000
The gap of the upper one-way elastic bond between the box and the impactor, m	δ_{01}	0.003
Stiffness of the lower one-sided elastic bond between the box and the impactor, kN/m	c_{r02}	120000
Viscosity coefficient of one-way elastic bonds c_{r02}, kg/s	b_{r02}	2000
The gap of the lower one-way elastic bonds between the box and the impactor, m	δ_{02}	0.003
Vibration exciter type IB-43-25	-	-
Synchronous angular speed of rotation of the electric motor, rad/s	ω_c	157
Nominal angular speed of rotation of the electric motor, rad/s	ω_n	156
Excitation force, kN	F_m	0–43
Static moment, kg×cm	L	0–175
Rated power of the electric motor, kW	N_n	4.2
Number of pole pairs of an electric motor	p	2
Power supply frequency, Hz	f_c	50
Overload capacity of the electric motor	ζ	2.4

The analysis of the dependencies shows that with such a number of steps per period *NH*=10, the excitation did not reach the established oscillation mode for 1000 periods. This is evidenced by the dependency shown in Fig. 2, which shows the change in time and angular speed of rotation of the electric motor shaft.

The casing and the sieve impactor perform less than 8 and less than 7 oscillation periods, respectively, during the last 10 excitation periods (Fig. 1), which indicates a calculated distortion of the oscillation characteristics as a result of an insufficient number of integration steps over the period.

The dependencies are obtained between accelerations of the sieve mass oscillations and the change in the angular speed of rotation of the electric motor of the vibrator at its basic parameters (Table 1) and the number of steps in the period *NH*=100 for the last 10 excitation periods out of 1000 calculated ones .

The analysis of the dependences shows that at 100 steps per period the sieve has entered the established oscillation mode. The box and the sieve impactor perform periodic vibro-impact oscillations (Fig. 3) with a period equal to the excitation period, and the angular rotation of the electric motor due to the influence of the reaction of the debalance masses of the vibration exciter and the sieve oscillations vary in the range from 156.75 rad/s to 157.14 rad/s.

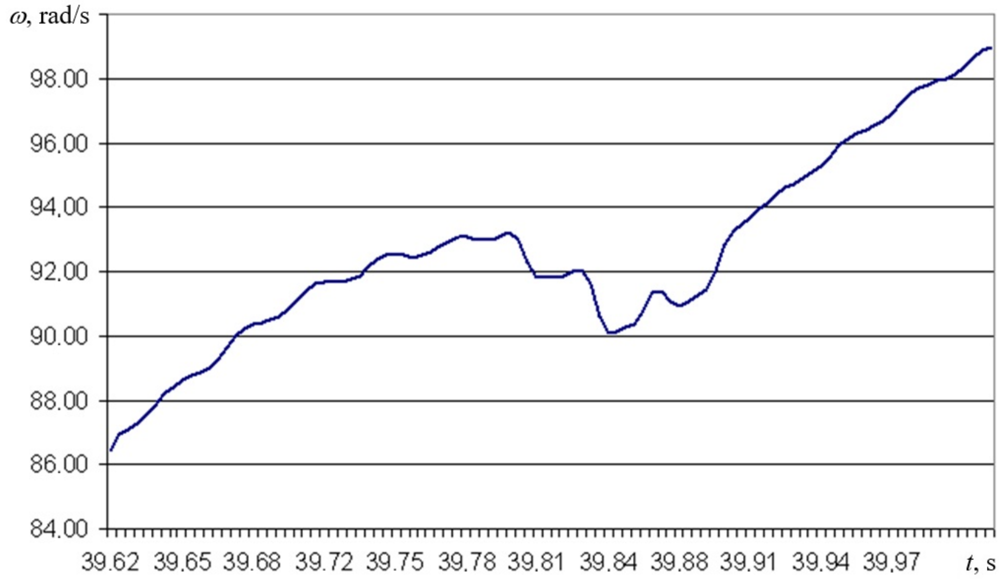

Figure 2 – Dependence of the change in the angular speed of rotation of the shaft of the electric motor of the sieve vibrator over the last 10 excitation periods

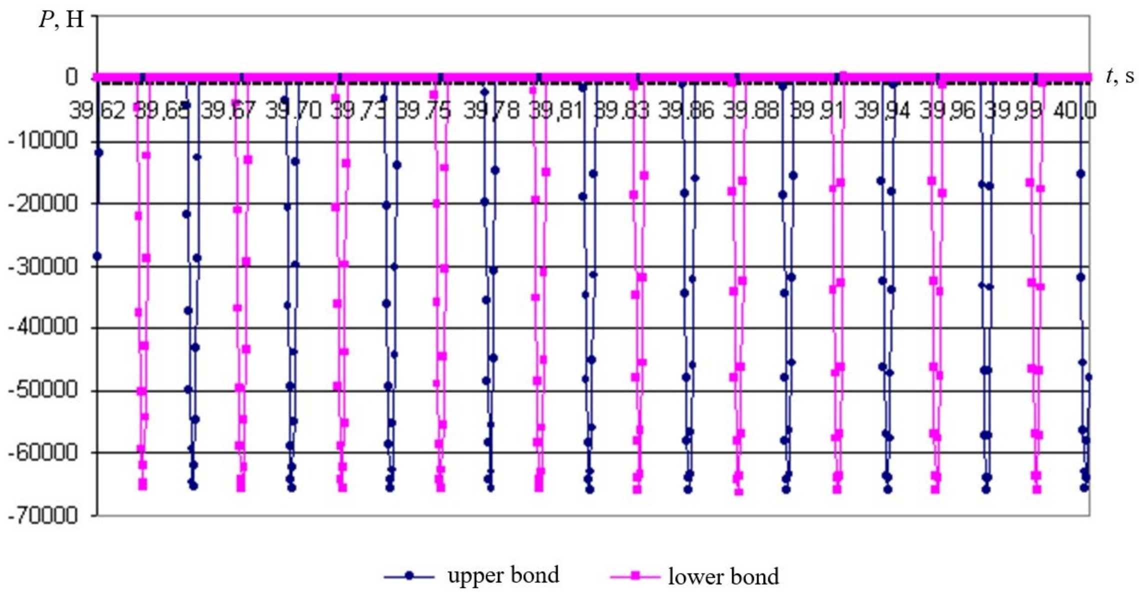

Figure 3 – Dependence of changes in reactions (- compression, + tension) of one-way elastic bonds for the last 10 excitation periods out of 1000 calculated at *NH*=100

The results of the performed studies show that the accuracy of displaying mass oscillations depends on the number of integration steps over the period and, therefore, when they become more complicated, for example, due to the asymmetry of the operating parameters of the sieve and the increase in the harmonics of the excited oscillation frequencies, it is necessary to increase this parameter. Thus, when the stiffness of the upper one-way elastic bond is increased by two times from 120000 kN/m to 240000 kN/m to reach the steady-state oscillation mode of the sieve, the *NH* parameter must also be increased. Fig. 4 and 5 show the phase diagrams of the casing oscillations, respectively, at *NH*=100 and *NH*=1000. Analysis of the phase diagrams shows that when the *NH* parameter is increased from 100 to 1000, the sieve with asymmetry of the parameters reaches the steady-state oscillation mode.

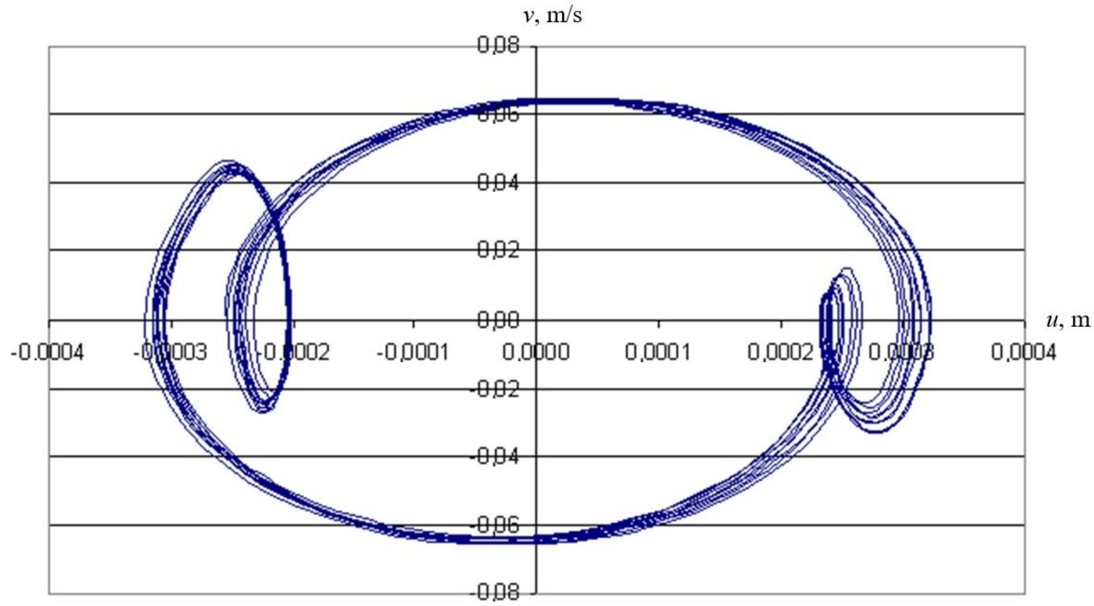

Figure 4 – Phase diagram of the sieve casing oscillations at *NH*=100 for the last 10 excitation periods out of 1000 calculated

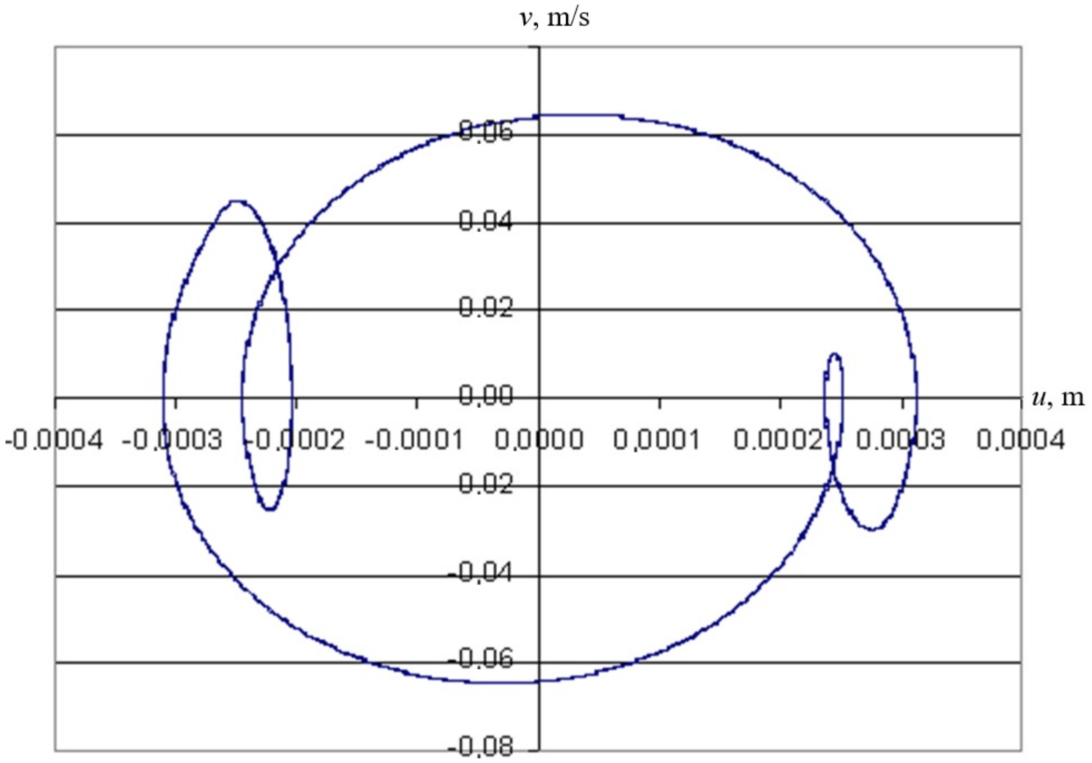

Figure 5 – Phase diagram of the sieve casing oscillations at *NH*=1000 for the last 10 excitation periods out of 1000 calculated

The results of the studies of the influence of the integration step over the period of the sieve excitation show that there is a limit value *NH*, starting from which the calculated values of the sieve parameters do not change with an increase in the number of steps per period. It is recommended to take the minimum limit value of the parameter 1000 steps per period. After completing the calculation, the parameter value should be increased to 2000, and the calculation repeated. To confirm the absence of the influence of *NH* on the values of the calculated sieve parameters, after carrying out calculations with certain values of the given sieve parameters, it is necessary to increase the number of steps by period and compare the calculation results with the previous ones. Their coincidence indicates the correctness of the selected integration step. As a rule, the limit value of the parameter does not exceed 3000.

The parameter the number of periods in time *NT* determines for how many periods of system excitation for each of the selected parameter values calculations will be carried out. The dependencies are obtained between the sieve mass movement for 160 periods of excitation (*NT*=160) from the moment the system starts and the basic operating parameters given in Table 1 with the number of steps per period *NH*=200.

The analysis of the dependencies shows that 160 excitation periods from the moment the system starts are sufficient for the oscillating sieve mass to reach steady-state vibro-impact modes of motion. The presence of vibro-impact oscillations is evidenced by the dependence of the change in the gaps between the one-way elastic bonds and the casing (Fig. 6). The maximum total gaps when the system reaches the steady-state vibration modes are more than 6 mm, which indicates the deformation of the one-way elastic bonds during the impact interaction of the masses (the basic gaps of the one-way bonds do not exceed 3.0 mm).

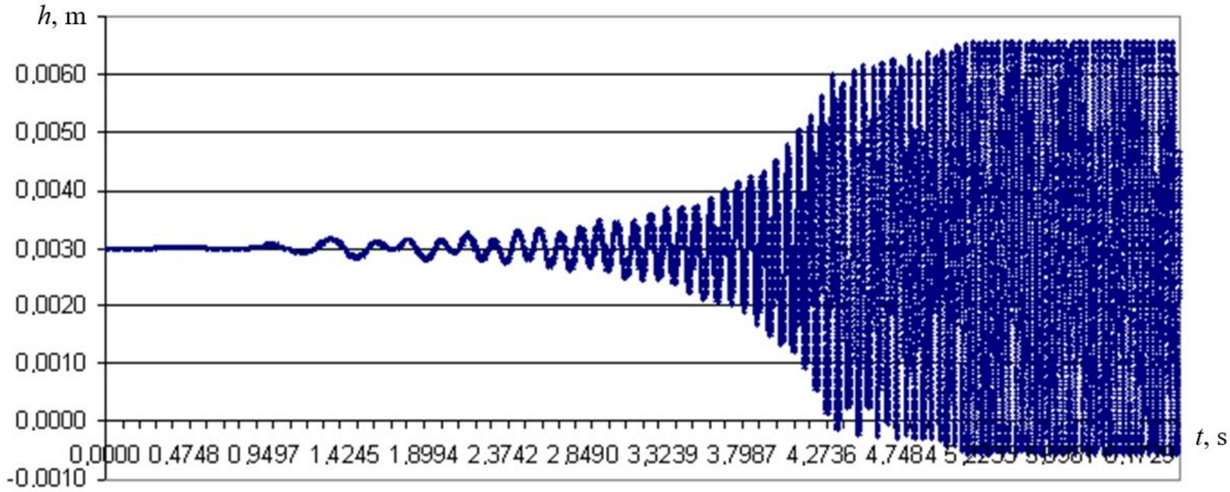

Figure 6 – Dependence of the change in the gaps between the one-way elastic bonds and the casing for 160 excitation periods from the moment of starting the vibration exciter motor

Therefore, with the operating parameters of the sieve given in Table 1, 160 excitation periods from the moment of starting the vibration exciter motor are sufficient for the sieve to enter the stationary (Fig. 7) vibro-impact oscillation mode. As can be seen in Fig. 9, the established vibro-impact oscillation modes of the sieve mass occur at 5.15 seconds and at a circular frequency of rotation of the vibration exciter motor equal to 156.67 rad/s.

The dependencies obtained of the accelerations of mass oscillations for 160 excitation periods from the moment of starting the sieve motor and *NH*=200. Analysis of the dependencies shows that in the motion modes, the acceleration of the sieve casing does not exceed 22.35 m/s^2, while the acceleration of the impactor reaches 210 m/s^2.

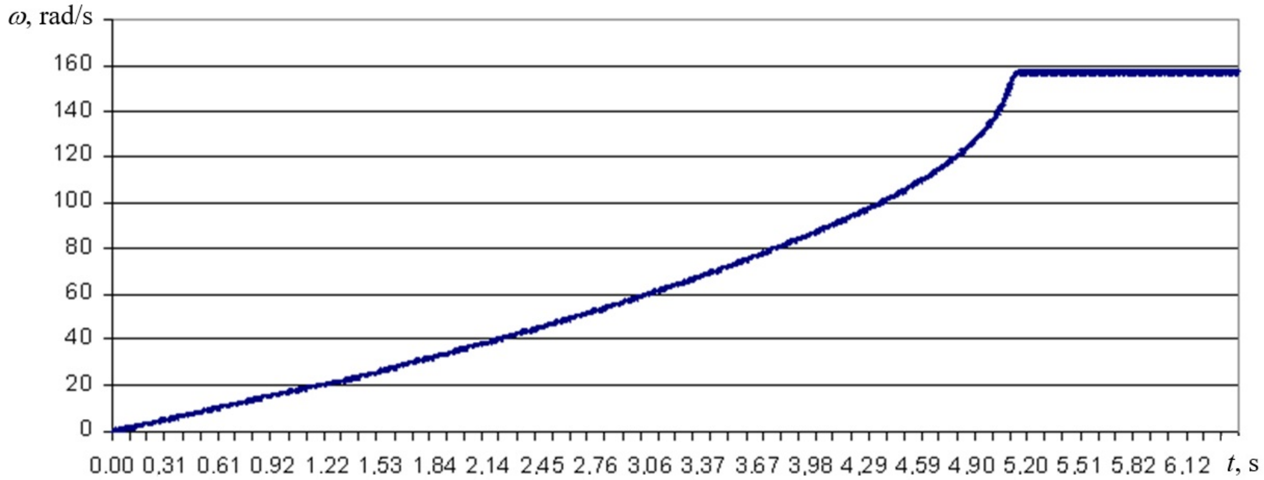

Figure 7 – Dependence of the change in the angular speed of rotation of the vibrator for 160 excitation periods from the moment of starting the sieve motor

According to the research tasks, the transitional modes of the sieve mass movement and their transition to the vibro-impact oscillation modes are important. Fig. 8 and 9 show the amplitude-frequency characteristics (AFC) of the sieve mass movements for 110 excitation periods from the moment of starting the electric motor at *NH*=290 and the basic sieve parameters (Table 1).

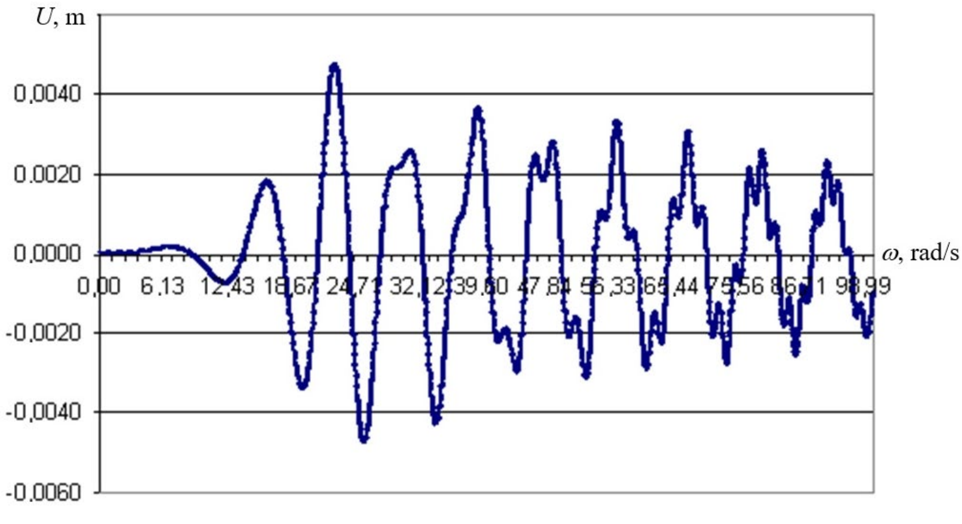

Figure 8 – Frequency response of sieve casing movements for 110 excitation periods from the moment of starting the electric motor at *NH*=290

The analysis of the dependencies shows that when the system starts in the frequency range of 16.35–25.62 rad/s, it has successfully overcome the first resonance at the oscillation frequency of the two-way elastic bonds between the casing and the base. After resonance, the amplitudes of the box oscillations gradually decrease, and the amplitudes of the impactor gradually increase, reaching maximum values in the vibro-impact oscillation modes. Thus, the sieve with the basic parameters (Table 1) and the power of the electric motor of the vibration exciter drive of 4.2 kW successfully overcomes the resonance of the system at the natural oscillation frequency of the two-way elastic bonds between the casing and the base and enters the vibro-impact oscillation mode.

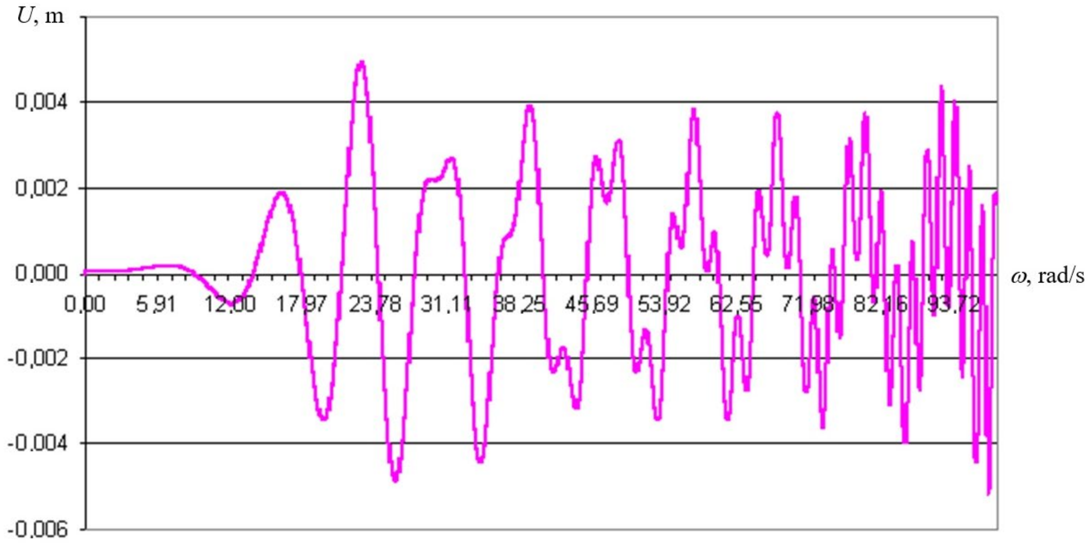

Figure 9 – Frequency response of the sieve impactor movements for 110 excitation periods from the moment of starting the electric motor at *NH*=290

According to the developed mathematical model, the influence of the power of the electric motor of the vibrator drive on the sieve transition to the vibro-impact oscillation mode can be studied in two ways:

- by the method of continuation by parameter, in our case, by the drive power, when the power of the electric motor of the sieve vibrator drive changes step by step in a given range. At the first stage of calculations, the system is started with the given initial conditions and the first power value from the accepted range. For the system start, the following initial conditions are assumed: initial position of the masses - U_{01}=0, U_{02} =0; initial velocity of the masses - V_{01}=0, V_{02}=0; initial angle of the position of the vibrator debalances - FV_{01}=0, initial angular velocity of rotation of the vibrator debalances - WV_{01}=0. At the second and subsequent stages of calculations, the values obtained at the last step of the previous stage are selected as the initial approximation of the sieve parameter values for further solving the equations of motion. At each stage, the number of calculations performed depends on the number of time periods *NT* and the number of steps per period *NH* (integration step), and the displayed calculation results are given by the number of recording periods from the last calculation periods;

- by the method of starting the system with fixed operating parameters of the sieve, and subsequent restarting the system with a changed value of the studied parameter, in the case of power, while fixing the results obtained at each stage of the research. Each time the system is started under the following initial conditions: initial position of the masses - U_{01}=0, U_{02}=0; initial velocity of the masses - V_{01}=0, V_{02}=0; initial angle of position of the debalances of the vibration exciter - FV_{01}=0, initial angular velocity of rotation of the debalances of the vibration exciter - WV_{01}=0. Since the characteristics of the system start are set by the drive parameters and, in particular, its power, the parameters of the sieve transition to the steady-state oscillation modes also change. In this case, the number of calculations performed at each power value is given by the number of time periods *NT* and the number of steps per period *NH* (integration step), and the displayed calculation results are given by the number of recording periods from the last calculation periods.

Fig. 10 shows the dependences of the change in the maximum and minimum values of the angular speed of the vibrator shaft rotation (or electric motor) obtained by the method of continuation by power at the basic parameters of the sieve (Table 1) and the change in the drive power in the range of 0.2–4.2 kW with a step of 2000; *NT*=1000. Analysis of the dependences shows that in the range of change in the drive power of 0.2–2.45 kW, the system power is not enough to overcome the oscillations of the first natural frequency of the two-way elastic bonds between the casing and the base. The system "hangs" at the first natural frequency; the Sommerfeld effect manifests itself [26, 27]. When the drive power reaches 2.7 kW, the system overcomes resonance and enters stationary vibro-impact oscillation modes.

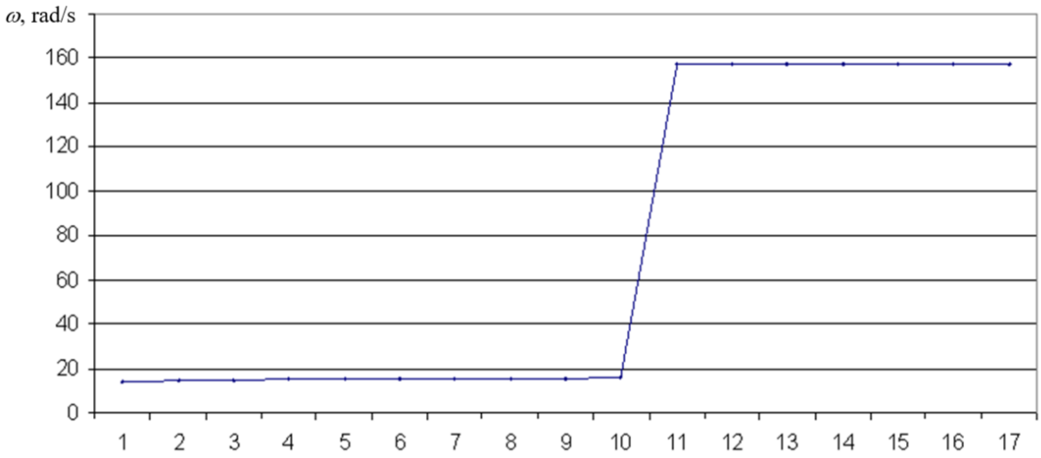

Figure 10 – Dependence of changes in the maximum and minimum values of the engine angular velocity when studying the system using the power extension method

The dependencies between the maximum and minimum movements and accelerations of the sieve mass when changing the drive power in the range of 0.2–4.2 kW with a step of 0.2 kW are obtained. Analysis of the dependences shows that in the range of increasing the drive power of 0.2–2.45 kW, the amplitudes of oscillations of the sieve mass increase, reaching values over 13 mm, and the amplitudes of accelerations change insignificantly. When the system overcomes the "hanging" at the natural frequency of oscillations of the retaining elastic bonds between the casing and the base and the excitation of vibro-impact modes, the amplitudes of oscillations of the casing decrease sharply and do not exceed 0.3 mm, and the amplitudes of oscillations of the impactor become equal to the sum of the gaps and deformations of the limited elastic bonds. At the same time, the amplitudes of the impactor accelerations in the vibro-impact modes reach more than 200 m/s^2, and the amplitudes of the casing accelerations do not exceed 23 m/s^2, which is important for ensuring the durability of the casing metal structure and effective cleaning of the drilling mud.

To verify the obtained results of the research by the method of continuation by the drive power, research was carried out by the method of continuation by frequency at fixed values of the drive power and by the second method - by the method of the next restart of the system with changed power values and fixed operating parameters of the sieve. In the research by the method of continuation by frequency, by setting the integration step for the excitation period *NH* (the number of steps per period) and the number of calculation periods *NT,* the system start algorithm is actually set. In the second research method by system start with fixed operating parameters of the sieve, the start algorithm depends only on the parameters of the sieve and its drive.

Fig. 11 shows the dependences of the accelerations of sieve mass oscillations for the last 10 excitation periods, obtained by the method of continuation by frequency with a step of 1 rad/s in the range of 1-157 rad/s, with the basic sieve parameters (Table 1) and drive power *N*=1.315 kW (*NT*=200; *NH*=2000).

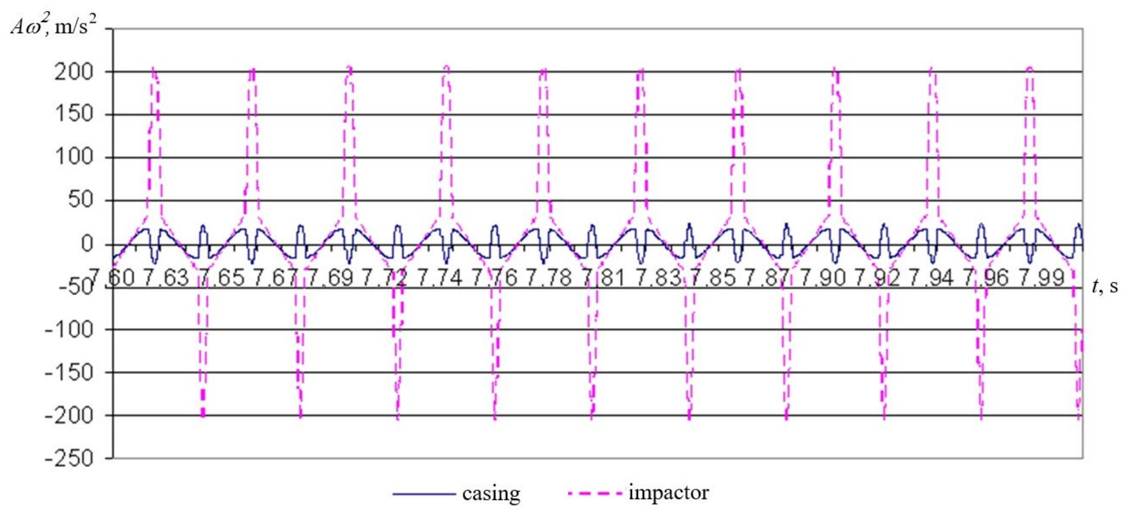

Figure 11 – Dependences of the accelerations of sieve mass oscillations for the last 10 excitation periods, obtained by the method of continuation by frequencies and at drive power *N*=1.315 kW

The analysis of the dependence shows that with such operating parameters and the research method (method of continuation by frequency), vibro-impact oscillations are realized in the sieve at a power of *N*=1.315 kW as with the method of continuation by power in the range of its change of 2.7–4.2 kW. Therefore, when starting the system at the frequency and power of the drive at *N*=1.315 kW, vibro-impact oscillation modes are realized in the sieve, which contradicts the results of research obtained by the method of continuation by power (see Fig. 11).

Studies using the second method, the method of sequential system start with fixed operating parameters and stepwise change of the studied parameter, showed that at a drive power of *N*=1.315 kW the system "hangs" at its own oscillation frequency of retaining bonds. These results coincide with the results of studies using the method of continuation by power. The dependencies between the change in the angular speed of the sieve vibrator rotation for the first 320 periods from the start moment and the last 32 out of 2000 calculated excitation periods at *N*=1.315 kW are obtained.

The sieve for 1000 excitation periods did not enters the vibro-impact oscillation mode, but "hung" on the natural frequency of oscillations of the retaining elastic bonds between the casing and the base.

Studies using the method of sequential restart of the system with fixed sieve parameters showed that the vibro-impact modes of motion in the system are excited at the power of the electric motor of the vibration drive, which is equal to *N*=1.422 kW. Fig. 12 and 13, respectively, show the dependences of the change in the angular speed of rotation of the sieve vibrator for the first 320 periods from the start moment and the last 32 out of 2000 calculated excitation periods at *N*=1.422 kW. It is seen that with such operating parameters the sieve enters the vibron-impact oscillation modes during the start process.

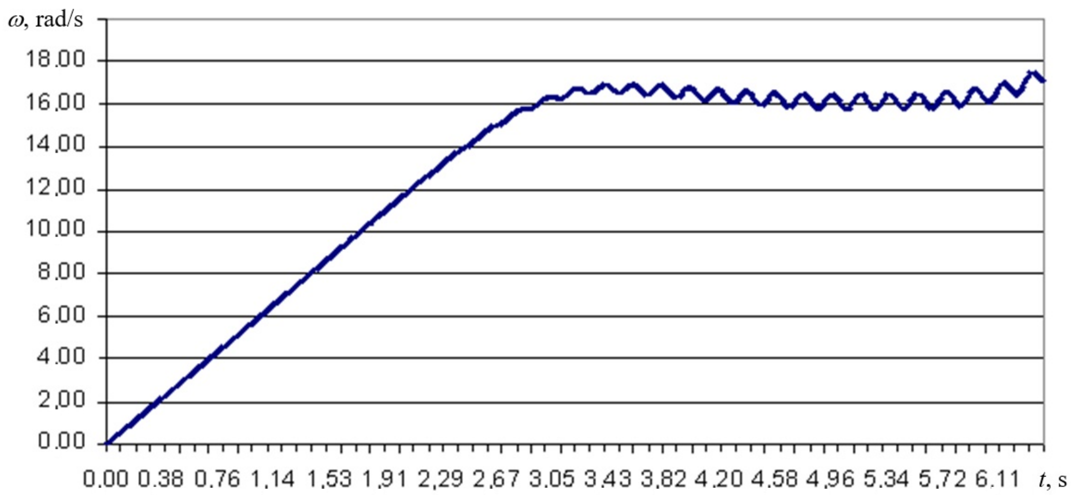

Figure 12 – Dependence of the change in the angular speed of the sieve vibrator rotation for the first 320 excitation periods from the start moment of at *N*=1.422 kW (*NH*=200)

4. Results

As a result of research into the influence of the power of the electric motor of the vibrator drive on the sieve entering stationary vibro-impact oscillation modes, it was found that, depending on the research method used, different engine power is required to overcome the "hung" of the system at the natural frequency of oscillations of the elastic bonds between the casing and the base and the beginning of excitation. Thus, with the method of continuation by power, the vibro-impact motion modes begin to be excited at a power of *N*=2.7 kW, with the method of continuation by frequency and power variation - at *N*=1.315 kW, when the system is restarted with a change in the drive power and the results of the research are fixed - at *N*=1.42 kW. Such a difference in power to overcome the "hung" and the beginning of excitation of vibro-impact oscillation modes is associated with the areas of existence and stability of vibro-impact systems. Any *n*-dimensional parameter space of a vibro-impact oscillatory system can be conditionally divided into three areas of existence and stability of excited oscillation modes: D_1 , D_2 and D_3 . The D_1 is the area of system parameters in which the vibro-impact modes are established regardless of the initial conditions (the conditions of the vibration system start). In this area, the amplitudes of forced oscillations of the mass m_2 (the impactor) in the original impactless system are always greater than or equal to the gaps established in the one-way elastic bonds of the vibro-impact system. Therefore, in the D_1 area, with gaps in the vibro-impact system smaller than or equal to the amplitudes of oscillations in the original impactless system, the vibro-impact modes of oscillations will always be excited.

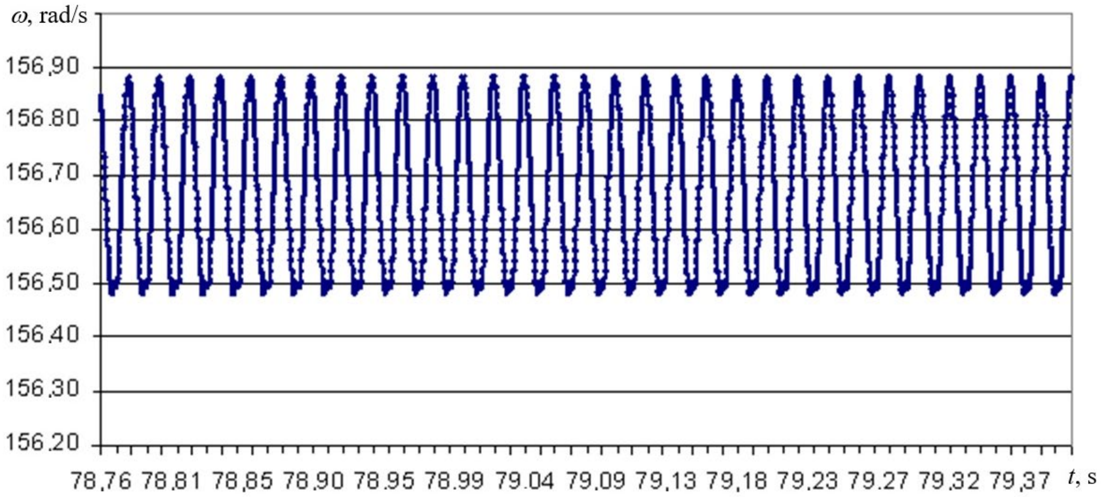

Figure 13 – Dependence of the change in the angular speed of the sieve vibrator rotation over the last 32 excitation periods out of 2000 calculated at N=1.422 kW (NH=2000)

The D_2 is the area of system parameters under which, regardless of the initial conditions, oscillations in the impactless mode will always be established. In this area, the amplitude of oscillations of the mass m_2 in the original impactless system is always less than the value of the gaps established in the one-way elastic bonds of the vibro-impact system.

D_3 areas, in which there are two modes of oscillation (attractors) [27]: vibro-impact and impactless. In this area, as well as in D_2, the amplitudes of oscillations of the mass m_2 in the original impactless system are always less than the values of the gaps established in the one-way elastic bonds of the vibro-inpact system. Therefore, in the D_3 area the amplitude of oscillations of the mass m$_2$ in the vibro-impact regimes is always greater than the amplitude of oscillations of this mass in the impactless system. Therefore, the D_3 areas are located within the parameters of D_2 area, adjacent to the D_1 area or with certain parameters of the vibro-impact system they can be partially located in the D_2 area. In addition, the D_3 areas are in the resonant area of the system parameters at the natural frequency of oscillations of the elastic bonds ND_{01} between the casing and the base. Each of the impact or impactless attractors has its own area of attraction in the phase diagram, so the realization of the oscillation mode is determined by the initial conditions of the system. In addition, the areas of existence of the vibro-impact modes D_3 depend on the direction of change of the parameters of the vibro-impact system (their increase or decrease). Therefore, such oscillatory systems are characterized by the so-called hysteresis [28].

Note, this is an important property of vibro-impact systems for practice. If a vibro-impact mode has arisen at some point in the space of the system state, for example, in the D_1 area, then with a continuous change in the system parameters or their discrete change with the largest step, the vibro-impact mode passes into the D_3 area and is stored until the trajectory of parameter changes enters the D_2 area. In this case, the amplitudes of oscillations of the mass m_2 in the vibro-impact mode can significantly exceed the amplitudes of the non-contact mode by more than an order. When the parameters of the D_3 area fall to D_2 area, there is a stop of the vibro-impact oscillations and the parameters of the system state "instantaneously" pass into the D_1 area.

Therefore, depending on the initial conditions of the state of the parameters in the vibration polyfrequency sieve at the same values, when the system is started, impactless or vibro-impact modes of oscillations can be excited in it. Violation of the vibro-impact modes of oscillations in the D_3 area of the parameters in the vibration polyfrequency sieve is possible only when they occur in the D_1 area and then at continuous change in the parameters of the system state or their discrete change with the largest step of the transition of values from the D_1 area to the D_3 area.

Therefore, when studying the oscillation modes by the method of continuation of the sieve motor power, if at the first power value when starting the engine the system does not overcome the "hung" and does not enter the vibro-impact oscillation mode, it will occur only when the system state parameters, with a further change in power, do not fall into the D_1 area, which occurs at power N=2.7 kW. This is due to the fact that with this research method the initial parameters of the system state at the next stage of calculation with the changed power are taken to be the same as at the last stage of integration at the previous power value. That is, the sieve motor starts from the value of the circular frequency of the sieve drive rotation QPW_{01}=0 only at the first power value, and at other power values, the calculation starts with the system oscillation parameters, as in the last integration stage at the previous power value. That is, at the following power change steps, the system restart from the value of the circular speed of the sieve drive QPW_{01}=0 does not occur, and the system enters the parameters of D_1 area only at $N \geq 2.7$ kW.

In the second research method, the method of phased system start with fixed sieve operating parameters and power change at each stage during restart, overcoming "hung" and excitation of vibro-impact modes of oscillations occurs at a power value equal to N=1.422 kW. Therefore, with this research method in the process of restarting with QPW_{01}=0, the system enters the parameters of D_1 area, overcomes "hung" and enters the vibro-impact mode earlier than with research method of continuation by power. That is, in the research by the method of continuation by power in the range of its change from 1.422 kW to 2.7 kW, the system, passing by the parameters of D_1 area immediately falls into the D_3 or D_2 areas, which eliminates the occurrence of vibro-impact modes of oscillation.

When studying the influence of the electric motor power on the system start by the method of continuation by frequency, an algorithm for starting the system that is not characteristic of the drive parameters is set (by setting the range and step of changing the angular speed of the electric motor). This leads to a delayed start, and, at some stage, the emergence of conditions for overcoming "hung" and excitation of vibro-impact modes in the D_1 area at slightly smaller (N=1.315 kW) values of the electric motor power than during the “natural” start (N=1.422 kW). Such a start of the electric motor of the vibration exciter drive of the mathematical model of the sieve is not characteristic of its physical model, the start of which depends on the parameters of the drive and its electric motor, and not on the algorithm for changing them.

Therefore, the influence of the drive power of a vibrating multi-frequency sieve on the start of the system and its entry into stationary oscillation modes should be studied by the method of starting the electric motor at given fixed sieve parameters, which most closely corresponds to the start of physical sieve models. The research method of continuation by parameter should be used for processes that simulate the real processes in physical sieve models. Such processes, for example, as the influence of the change in the mass of the impactor m_2 on oscillation modes, modeling the influence of the change in the attached mass of the technological load or changes in the characteristics of elastic bonds, modeling the change in their properties, for example, under the influence of temperature heating or aging.

5. Conclusions

The impact of the input parameters of the mathematical model of a vibrating multi-frequency sieve for cleaning drilling muds with limited vibration exciter power on the research results was assessed, and their identification was performed. This allowed us to investigate and select the research methods of the mathematical model that best correspond to the dynamic processes of entering and establishing the stationary vibro-impact oscillation modes of a multi-frequency sieve for effective cleaning of drilling muds.

As a result of the work, it was established that:

- the research method of the mathematical model of a vibrating multi-frequency sieve used for establishing the regularities of the influence of the power of the electric motor of the vibration exciter on the sieve reaching on stationary vibration modes, which most closely corresponds to the dynamic processes of reaching and establishment of stationary vibro-impact oscillation modes, is the method of sequential start of the model with selected parameters of the electric motor;
- the research method of continuation by the parameter of the mathematical model of the sieve should be used to study the regularities of the influence of changes in the mass of the technological load or the properties of elastic bonds, for example, under the influence of temperature heating, on the modes and parameters of oscillations of a vibrating multi-frequency sieve.
- by comparing the obtained results of research of a single-mass model with elastic vibration limiters and limited power of the vibration exciter with the results of research of such a model with an ideal source of vibrations, we were able to confirm the correctness of the assumptions made when choosing the model of an asynchronous electric motor.

Conflict of interest

Authors state no conflict of interest.

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ІДЕНТИФІКАЦІЯ ПАРАМЕТРІВ ТА ДОСЛІДЖЕННЯ МАТЕМАТИЧНОЇ МОДЕЛІ ВІБРАЦІЙНОГО ПОЛІЧАСТОТНОГО СИТА ДЛЯ ОЧИЩЕННЯ БУРОВИХ РОЗЧИНІВ

Шевченко В., Шевченко Г., Черненко А.

Анотація. Для дослідження процесу та встановлення закономірностей зміни силових, енергетичних та режимних параметрів вібраційного полічастотного сита та обґрунтування його раціональних параметрів проведено ідентифікацію параметрів математичної моделі та методу дослідження впливу потужності електродвигуна вібробзбудника на вихід вібраційного полічастотного сита для очищення бурових розчинів на стаціонарні режими коливань. Здійснено оцінку впливу вхідних параметрів математичної моделі сита з обмеженою потужністю вібрchoзбудника на результати досліджень та виконано їх ідентифікацію. Проведено дослідження та вибрано методи досліджень математичної моделі, які найбільше відповідають динамічним процесам виходу та встановлення стаціонарних віброударних режимів коливань полічастотного сита для ефективного очищення бурових розчинів. Методом досліджень математичної моделі вібраційного полічастотного сита по встановленню закономірностей впливу потужності електродвигуна вібрoзбудника на вихід сита на стаціонарні режими коливань, який найбільш відповідає динамічним процесам виходу та встановлення стаціонарних віброударних режимів коливань, є метод послідовного запуску моделі з обраними параметрами електродвигуна. Метод досліджень продовження за параметром математичної моделі сита слід застосовувати для дослідження закономірностей впливу зміни маси ударника, моделювання зміни приєднаної маси технологічного навантаження або властивостей пружних зв'язків під впливом температурного нагріву або старіння на режими та параметри коливань вібраційного полічастотного сита. Показано, що робочих параметрах сита та при зміні прискорень коливань мас сита у діапазоні 1-157 рад/с і методі продовження по частоті в ситі при потужності N=1,315 кВт реалізуються віброударні коливання як і при методі продовження за потужністю в діапазоні її зміни 2,7–4,2 кВт. Отже, при запуску системи за частотою та потужністю приводу при N=1,315 кВт у ситі реалізуються віброударні режими коливань. Шляхом порівняння отриманих результатів досліджень одномасової моделі з пружними обмежувачами коливань та обмеженою потужністю вібрoзбудника з результатами досліджень такої моделі з ідеальним джерелом коливань дозволили підтвердити правильність прийнятих припущень при виборі моделі асинхронного електродвигуна.

Ключові слова: ідентифікація параметрів, математична модель, вібраційне полічастотне сито, очищення бурових розчинів, закономірності, режими коливань.