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RESULTS OF TESTING AND MODELLING THE "DRILLING RIG WITH HYDRAULIC VIBRATOR – ROCK" SYSTEM

A promising device that increases the efficiency of drilling wells in hard and super hard rocks is a drilling rig with a cavitation hydraulic vibrator. Inside it due to periodic growth, separation and collapsing of cavitational pockets, the pressure shock oscillations are realized in drilling mud. They are transformed into longitudinal vibrations of rock-breaking tool with frequencies of 1–20 kHz and values of vibration accelerations from 500 to 3200 g. At repeated impact of power impulses of the rock-breaking tool, the destruction of rock becomes fatigue. As a result of resonance processes in the system of "drilling rig with hydraulic vibrator – rock" and the development of a network of micro-cracks, the rock discontinuity occurs at the stresses lower than the break-down point of the rock. It leads to the increase in drilling speed, wear resistance of drilling tools, improvement of stabilization and steadiness of drilling string functioning.

Purpose. To determine the longitudinal vibrational accelerations of the drilling tool at its contact with the destroyed rock taking into account the forces acting in the axial direction on the structure of the drilling rig.

Methodology. Methods are based on the experimental and theoretical study on dynamic interaction of rock-breaking tool longitudinal oscillations with the rock.

Findings. The results are presented in the form of estimated dependences of the peak-to-peak values of fluid pressure oscillations and vibrational accelerations of rock-breaking tool on the value of cavitation parameter and their comparison with the experimental data.

Originality. It is established that:

- taking into account the contact of the drilling tool with the destroyed rock and forces acting along the axial direction on the structure of the drilling rig in the mathematical model of longitudinal oscillations of the drilling rig allows obtaining a satisfactory agreement of the calculated and experimental parameters of the fluid pressure oscillations and vibrational accelerations in the rock-breaking tool cross-section;
- for the given design of the hydraulic vibrator the rational regimes of its operation are determined (according to the dependence of the peak-to-peak values of vibrational accelerations on the cavitation parameter) as well as the length of the drilling rig (according to the distribution of the peak-to-peak values of vibrational accelerations along the axial length of the drilling rig).

Practical value. The mathematical model of the "drilling rig – rock" system allows establishing the rational regime of operation of the cavitation hydraulic vibrator at the design stage to implement acceptable levels of vibrational accelerations on the rock-breaking tool.

Keywords: *drilling rig, cavitation hydraulic vibrator, rock-breaking tool, vibrational acceleration, mathematical modeling*

Introduction. Rotary-percussive drilling of the well with the hydraulic impact machines is one of the efficient drilling method [1]. But in the course of operation, the developers of hydraulic hammers identified a number of their inherent flaws, which, to certain extend, calls in doubt their wide spreading. Thus, the presence of rapidly wearing moving parts, springs and rubber cuffs in their design reduces the inspection period to 25 hours. Furthermore, hydraulic impact machines, adversely affecting the pump through the pressure oscillations, cause increased wear of its parts and reduce drilling efficiency due to unambiguous dependence of downhole power on the characteristics of the pump.

A progressive technical direction to eliminate these drawbacks is a method of creation of dynamic loads on a rock-breaking tool with a cavitation generator of fluid pressure oscillations (hereinafter referred to as generator) [2]. It represents the Venturi tube of special geometry. This method is implemented in the development of a drilling rig (DR) with a hydraulic vibrator [3, 4] in the flow part of which a generator is mounted. In the flow part of the generator, the stationary fluid flow is converted into a periodically stalling cavitation flow, and high-frequency impact oscillations are generated in the hydraulic vibrator, which are transmitted to the rock-breaking tool in the form of vibration accelerations. The use of this type of generator makes it possible to realize pressure impulses of fluid exceeding the pressure generated at the outlet of the pumping unit with the possibility of changing the impulse frequency in the range of 200–10000 Hz. There are no moving parts in the generator. It does not require additional power sources, is easy to manufacture and fits well into existing equipment. It is also important that the generator does not affect the pump, since pressure oscillations are not transmitted before its installation place.

The correctness of the choice of the proposed method is confirmed in the works by Dzoz N. A. in the study of DR on

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hydraulic and drilling stands and pilot tests during the construction of wells. It has been established that the imposition of longitudinal vibration accelerations on the drilling tool (DT) during the construction of wells in solid rocks leads to the increase in drilling speed, wear resistance of drilling tool, improvement of stabilization and steadiness of drilling string functioning.

Literature review. Tendencies to an increase in drilling speed using hydrodynamic cavitation as a source of fluid pressure pulsations and vibration loads of drilling tools are presented by researchers from the USA, China and Canada at symposia and exhibitions on geomechanics and well drilling.

For example, in papers [5, 6], an experimental study was performed on the improvement of the operational characteristics of a drilling tool. This is achieved by increasing the speed of removal of the crushed material from the zone of contact of the surfaces of the bit cutters and rock during the drilling process. Maximizing the positive effect of cleaning the well bottom occurs due to cavitation effects in the high-pressure flow of drilling mud in the bit nozzle, as well as due to microseismic response (vibration) to the mechanism of rock failure.

Data on maximizing the drilling speed by creating mud pulsations, which lead to more efficient removal of sludge from under the bit, are also given in works [7, 8]. It has been established that when drilling held with the cavitating impulse tool, more efficient cutting of the rock and transportation of drill cuttings occur, as well as the reduction of friction in the drilling string.

With the exploration and development of oil and gas in difficult geological conditions in ultra-deep wells (more than 6000 m) in the western region of China, the researchers faced with difficult problems. With an increase in the depth of the well, the drilling speed decreased significantly, and its cost increased greatly, which directly affects the rate of development of new discoveries. To overcome the above problems, in China a new drilling tool was developed [9] – a special bit with a hydraulic impulse generator of cavitation jet inside it, as shown in Fig. 1.

The test results of this tool showed that when the flow rate of the flushing fluid is from 27.5 to 32 l/s, the hydraulic pulse generator creates fluid pressure oscillations with peak-to-peak amplitude of $\Delta P \approx 2.1{-}2.2$ MPa with a carrier frequency of 10 Hz. From Fig. 2 [10] it is also shown that the main harmonic of these oscillations is superimposed by pulsations of increased frequency of approximately 80 Hz with peak-to-peak amplitude of $\Delta P \approx 0.56{-}0.60$ MPa.

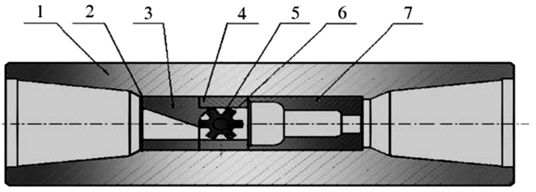

Fig. 1. Hydraulic pulsed cavitation jet generator configuration [9]:
1 – Basement; 2 – Snapring; 3 – baffle; 4 – Impeller bed; 5 – Impeller shaft; 6 – impeller and bushing components; 7 – Cavitating oscillation cavity

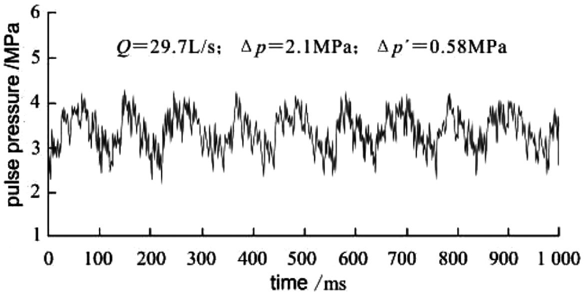

Fig. 2. Oscillogram with recording of the oscillatory process of a hydraulic impulse generator [9]

The pulsating jet, cavitation erosion and the local effect of negative pressure in the bottomhole accelerate the destruction of the rock, improve the cleaning of the drilling tool and the removal of sludge from the well. Field experiments in three deep wells showed that when drilling with this rock-cutting tool, the drilling speed increases by 30–60 %.

It should be noted that the frequency of the pulse exposure and the level of vibration loading of the rock-breaking tool of DR is significantly higher than the frequencies and levels of vibration loading in the devices proposed in the studies [5–9]. This allows us to eliminate the drawbacks indicated in [10], when “under deep drilling conditions in strong rocks there occur strong vibrations with frequencies up to 20 Hz, which can lead to a decrease in drilling speed and premature equipment failure”.

The choice of rational parameters of impulse action in the above studies was carried out on the basis of experimental studies.

The theoretical determination of the DR oscillation parameters, taking into account the fluid pressure pulsations, was undertaken in [11]. It proposes a finite element mathematical model of DR longitudinal oscillations with a hydraulic vibrator. The mathematical model describes the time variation of the attached and collapsing cavitation cavity in the flow part of the hydraulic vibrator and the oscillations in the mass flow rate and pressure of the drilling mud caused by this process. These vibrations are transformed into longitudinal vibrations of the DR structural elements. The results of numerical simulation allow obtaining not only qualitative, but also quantitative coordination of the calculated and experimental parameters of the pressure oscillations of the fluid and the longitudinal vibration accelerations of the structure in various sections of the drilling rig. Experimental data given in [11] were obtained for a drilling rig when it is rigidly mounted on a hydraulic stand without taking into account its axial load and the contact of the drilling tool with the rock to be destroyed. However, under industrial conditions, the DR structure will be additionally affected by the forces of the weight of the drill pipe and the axial load created by the hydraulic cylinder, as well as the forces of interaction of the rock-breaking tool with the rock.

Finally, all of this can significantly affect the calculated level of vibration load on the drilling tool and the effectiveness of its work.

In view of the above, taking into account the contact of the drilling tool with the rock to be destroyed and the axial forces acting on the DR in the mathematical model is a recent scientific and technical problem.

This is due to the fact that during the development of the DR at the design stage, the optimization of the operation of a hydraulic vibrator is based precisely on estimation of the vibration loading level of a rock-breaking tool, which must be performed using mathematical modeling.

The purpose of this work is to determine the longitudinal vibration accelerations of the rock-breaking tool during its contact with the rock to be destroyed, taking into account the forces acting in the axial direction on the construction of the drilling rig.

To achieve this goal the following tasks were solved:

- experimental determination of the vibration load on the rock-breaking tool when the DR is immersed in a well with an axial load of 9.8 kN;
- theoretical investigation of the vibration load level on the drilling tool, taking into account the strength, elastic and dissipative characteristics of the rock to be destroyed and the forces acting in the longitudinal direction on the DR construction;
- determination of the rational regime of operation of the hydraulic vibrator and the impulse effect of the DR on the

rock-breaking tool based on the analysis of the available estimated and experimental data.

Experimental determination of longitudinal oscillations of the rock-breaking tool of the drilling rig. The design of the drilling rig is shown in Fig. 3.

It consists of the hydraulic vibrator – *5*, comprising generator – *2*, drilling pipe – *1* and rock-breaking tool – *6*. Here, there is schematically shown a settled cavern formed in the flow part of the generator – *3*, and a detached cavern that is carried downstream into the flow part of the hydraulic vibrator – *4*.

General schematic representation of the drilling rig test with the optimal geometric parameters in the well with the depth of 87 m is represented in Fig. 4.

The static pressures at the inlet to the DR P_1 and at its exit P_2 were calculated using the formulas: $P_1 = (P_d + 0.83)$ MPa and $P_2 = (P_b - 0.87)$ MPa, where P_b is the backpressure; P_d is the pressure of the drilling fluid generated by the pump.

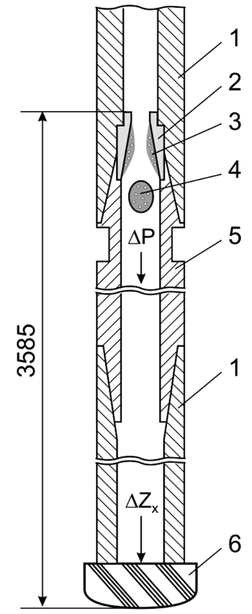

Fig. 3. Design of the drilling rig:

1 – drilling pipe; 2 – generator; 3, 4 – settled cavern and its separated part; 5 – hydraulic vibrator; 6 – rock-breaking tool

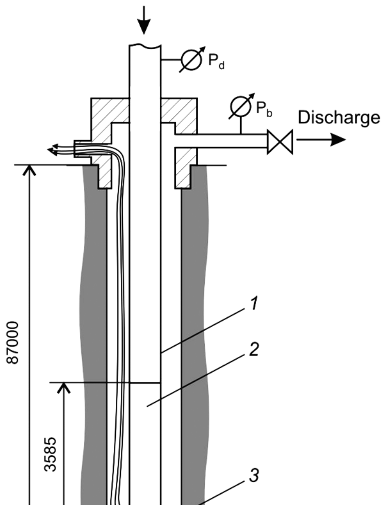

Fig. 4. Schematic representation of the drilling rig test in the well:

1 – drilling tube; 2 – drilling rig; 3 – rock-breaking tool

On the drilling tool *3* there were installed piezoelectric sensors for amplitude and pulsation frequencies of fluid pressure I-24.2141 (with measurement limits from 0 to 10 MPa and a natural frequency of 120 kHz) and sensors for vibration accelerations ABC-034. The signal from each sensor arrived at the switchboard via cable line *5*, made of cable RK-50.

With this design of the drilling rig, 3 tests were performed differing in pressure at the inlet, $P_d = 3$, 4 and 5 MPa. The drilling tool was in contact with the rock (granite).

The main geometrical parameters of the DR are given in the Table. 1.

The results of this DR test with discharge pressure $P_d = 4$ MPa and flow rate of flushing fluid $Q = 2.3$ l/s and with axial load $F = 9.8$ kN are shown in Table 2.

Cavitation parameter τ that is given in the table, used as a criterion for the dynamic similarity of the regime of liquid cavitation flow, is the ratio of the pressure at the generator output to the pressure at its input, i. e.

$$\tau = {}^{p_2}\!\!\diagup_{p_1}.$$

The numerator of this parameter includes the pressure value, under the action of which the cavity collapses, and the denominator includes the pressure that determines the velocity head of the fluid flow, under the action of which cavity appears and grows in the generator.

Vibration acceleration values ΔZ_x were determined as average values for two sensors.

Considering that the shapes of cavitation oscillations of fluid pressure behind the generator are noticeably different from the harmonic oscillations, in the analysis of experimental and theoretical research studies on the dynamic parameters of the DR, no amplitudes were used, but peak-to-peak values of fluid pressure oscillations – ΔP and vibration accelerations along the axial direction of DR – ΔZ_x.

Table 1

The main geometrical parameters of DR

Geometrical parameter	Size
The diameter of the critical section of the generator, mm	6
The length of the critical section of the generator, mm	8.2
The diameter of the diffuser at the output of the generator, mm	24
The length of the generator diffuser, mm	51
The opening angle of the generator diffuser, °	20
The diameter of the hydraulic vibrator channel, mm	24
The length of the hydraulic vibrator channel, mm	420
The diameter of the drilling pipe, mm	76
The length of the drilling rig, mm	3585

Table 2

The results of DR test

τ	ΔP, MPa	ΔZ_x, g	*f*, Hz
0.100	4.80	1960	196
0.137	6.00	2793	326
0.161	5.90	3201	374
0.184	5.15	2564	423
0.200	4.30	1570	508
0.340	3.20	928	793
0.415	2.78	1401	995
0.475	2.55	1027	1188

The values of these parameters were determined as the difference between their maximum and minimum

$$\Delta P = p_{\max} - p_{\min};$$

$$\Delta Z_{\underline{x}} = Z_{x\max} - Z_{x\min}.$$

The dynamic process frequency f of the DR, given in the table, was determined on the basis of the analysis of the time dependence of the fluid pressure in the hydraulic vibrator (oscillations dominant mode).

As a result of the tests, it was established that the dynamic process, determined by the development in the generator of the periodically separated cavitation regime, is characterized by an impact form of pressure oscillations in the flow part of the hydraulic vibrator. These vibrations propagate along the entire length of the DR and are converted into vibration accelerations of the drilling tool. For example, at $P_d = 4$ MPa, $\tau = 0.16$, the dominant frequency of cavitation pressure oscillations in the flow part of the hydraulic vibrator is 374 Hz, and the frequency of longitudinal vibration accelerations of the DR rock-breaking tool ≈ 938 Hz with average values of $\Delta Z_x \approx 3200$ g.

Analysis of test results differing by inlet pressure showed that increasing the inlet pressure of the hydraulic vibrator leads to an increase in the vibration acceleration values in the cross section of the drilling tool from 2280 g (at $P_d = 3$ MPa) to 4580 g (at $P_d = 5$ MPa).

Numerical determination of the longitudinal oscillations of the drilling rig, taking into account the axial load and contact with destructible rock. Taking into account the fact that during the experimental research in the well, the movement of the DR with a high-frequency hydraulic vibrator in the transverse direction is limited by the walls of the drilled rock, mathematical modeling of the DR as a dynamic system was performed under the assumption that its construction carries out vibratory motion along the axis of the fluid flow in its flow part. That is, only longitudinal oscillations of the drilling rig construction were considered. This limitation is also due to the axial symmetry of the construction itself and the directionality of the total component of the forces acting on the DR construction [12].

Mathematical modeling of longitudinal oscillations of the drilling rig was performed by integrating the system of nonlinear differential equations given in [11] and describing the dynamic processes of the DR construction and the liquid medium in its flow part using the finite element method. In contrast to the mentioned work, the boundary condition at the end of the DR part of interest (i.e., on the rock-breaking tool) while modeling longitudinal oscillations, is set with taking into account the following: the lower part of the drilling rig is “pressed” to the surface of the model soil with an axial force of 9.8 kN, which implies taking into account the dynamic properties of the rock during the modeling of its interaction with the rock-breaking tool. Elastic-dissipative properties of the rock are described by introducing a separate rigidly fixed finite element (rock) with a large equivalent mass and damping coefficient into contact interaction with the finite element of the DR construction (describing the movement of a rock-breaking tool). The modulus of elasticity and density of the rock were determined from reference data on its acoustic impedances.

As a result of the numerical integration of the system of differential equations by the Runge-Kutta method, the dependences of the displacement process, vibration velocity and vibration accelerations of structural elements, pressure and fluid flow rate, volumes of the attached and collapsing cavity in the flow part of a hydraulic vibrator on the time are determined.

For example, Figs. 5 and 6 show the processes of time variation of the calculated pressure dependences in the DR flow part and vibration accelerations in the cross section of a drilling tool. These dependences are determined for the value of discharge pressure being equal to 4 MPa, and the cavitation parameter $\tau = 0.16$. and 0.34.

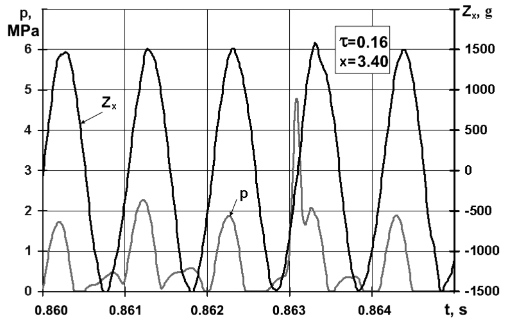

Fig. 5. The change in time of the calculated dependences of pressure and vibration accelerations in the cross section of the rock-breaking tool for $\tau = 0.16$

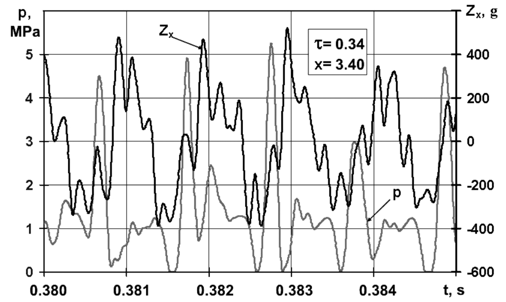

Fig. 6. The change in time of the calculated dependences of pressure and vibration accelerations in the cross section of the rock-breaking tool for $\tau = 0.34$

As follows from the nature of the above dependences of the pressure of the liquid medium and vibration accelerations in the cross section of the BS rock-cutting tool on time, the oscillatory process is pulsed. With the value of the cavitation parameter $\tau = 0.16$ (Fig. 5), the main harmonic of the frequency of cavitation oscillations of pressure was 357 Hz, and the peak-to-peak value of the oscillations was $\Delta P \approx 5.1$ MPa. It can be seen from the results of calculation that the frequency of vibration accelerations ≈ equal to 962 Hz is superimposed on the main harmonic of the frequency of cavitation oscillations of pressure. This is due to the dynamic interaction of the drilling rig construction and the liquid medium in its flow part.

The calculated value of the vibration accelerations on the DR drilling tool is in satisfactory agreement with the experimental data given in Table 1, and is approximately equal to 3200 g.

When the cavitation parameter $\tau = 0.34$ (Fig. 6), the dominant frequency of pressure oscillations in the flow part of the hydraulic vibrator equals ≈ 800 Hz, with the average value of the oscillation peak-to-peak value $\Delta P \approx 3.6$ MPa and vibration accelerations on the rock-breaking tool $Z_x \approx 990$ g.

On the main harmonic of the frequencies of cavitation oscillations of pressure and vibration accelerations on the rock-breaking tool it is superimposed oscillation frequency that approximately equals to 4700 Hz.

Taking into account the measurement errors during the experiment and data processing and the calculation errors, satisfactory agreement of the theoretical and experimental data was obtained.

Comparative analysis of theoretical and experimental studies. Fig. 7 shows the calculated and experimental dependencies of the pressure peak-to-peak values of ΔP of the rock-breaking tool (in the sensor installation section) on the cavitation parameter τ that changes in the range from 0.1 to 0.475 and the discharge pressure P_d which equals 4 MPa.

The nature of the presented dependences is nonlinear. With an increase of the parameter τ value from 0.1 (with an increase in the backup pressure at P_d = const), the peak-to-

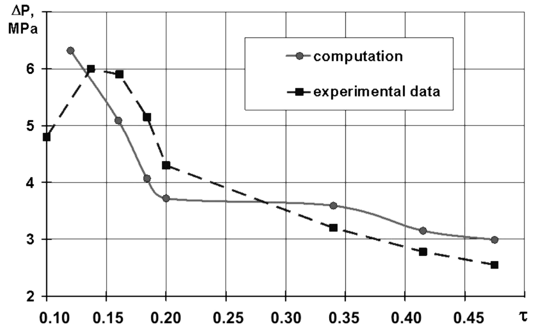

Fig. 7. Calculated and experimental dependences of the rock-breaking tool peak-to-peak pressure oscillations values on the cavitation parameter τ

peak values of pressure oscillations increases and reaches the maximum value of 6 MPa at $\tau = 0.137$ (according to the experimental dependence), and then decreases.

The maximum of the peak-to-peak value of the oscillatory quantity of pressure in the sensors installation cross section 1 exceeds the discharge pressure P_d by 1.5 times. In the entire range of variation of the τ value, not only qualitative was obtained but also quantitative agreement between the calculated peak-to-peak values of pressure oscillations and the experimental data.

A comparison of the theoretical dependences and experimental data oa the peak-to-peak values of the vibration accelerations ΔZ_x on the cavitation parameter τ in the cross section of the rock-breaking tool is shown in Fig. 8 and indicates satisfactory agreement of the results.

From the analysis of the data from this figure, it is followed that the increasing of forced oscillations amplitudes of the drilling fluid pressure at the cavitation number equals 0.1–0.16 results in the increase of the vibration accelerations amplitudes of the rock-breaking tool. The maximum peak-to-peak value of the vibration accelerations on the rock-breaking tool for this design was obtained at $\tau = 0.16$ and is approximately 3200 g.

At the same time, it is necessary to note the existence of a resonant operation regime of the drilling rig, which is a consequence of the convergence of the natural oscillation frequencies of the DR construction and the oscillation frequency of the drilling mud due to the "operation" of the cavitation generator.

This phenomenon is typical for the cavitation parameter equal to the $\tau = 0.415$, which is confirmed by both experimental and theoretical dependences $\Delta Z_x = f(\tau)$.

Fig. 9 presents the calculated curves of the dependence of the pressure oscillations ΔP and longitudinal vibration accelerations ΔZ_x along the axial length of the drilling rig at the cavitation parameter which equals 0.16 and 0.415. It also shows the experimental values corresponding to the sensors installation cross section on the rock-breaking tool (ΔP – ●, ΔZ_x – ▲).

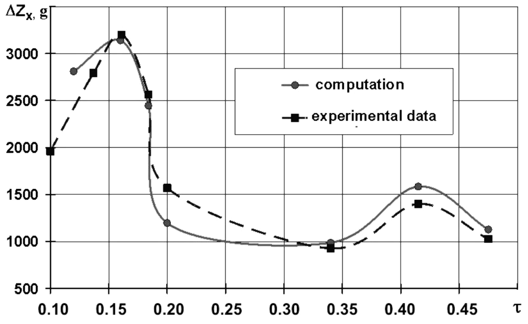

Fig. 8. Calculated and experimental dependences of the peak-to-peak values of vibration accelerations of the rock-breaking tool on the cavitation parameter

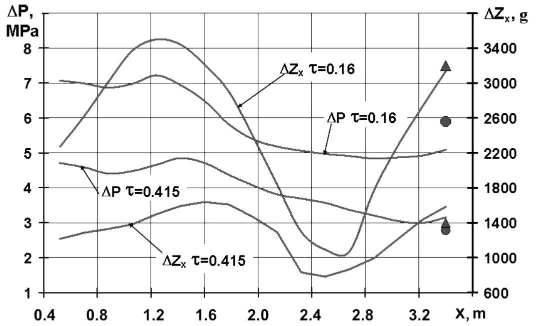

Fig. 9. The distribution of the estimated peak-to-peak values of pressure oscillations and vibration accelerations along the axial length of the drilling rig when $\tau = 0.16$ *and* 0.415

From the dependences presented above, it can be seen that in the sensor installation section on the rock-breaking tool there is a satisfactory agreement of the results of the performed modeling with the experimental data of the pressure peak-to-peak vales ΔP and vibration accelerations ΔZ_x.

It should be noted that the choice of the length of the drilling rig the study of the dynamic characteristics of which is given in this work, was carried out by shortening the drill pipe (Fig. 3, pos. 1 before the rock-breaking tool) in 0.6 m steps followed by experimental determination of ΔP and ΔZ_x. At DR lengths of 2.95 and 2.35 m, the decrease in the levels of ΔP and ΔZ_x values was observed. This is confirmed by the data in Fig. 9. From this figure it is clear that in the range of the specified DR lengths there is a "failure" of the pressure and vibration acceleration oscillatory values.

Thus, following the results shown in Fig. 9, it is possible to determine the rational length of the drilling rig with this design of the hydraulic vibrator, depending on the flow regime in it, defined by the parameter τ.

When the DR is working, with the value of $\tau = 0.16$ (which is installed by the choke on the drain, Fig. 4), the length of the drilling rig is $l_{dr} \approx 1.3$, which allows providing the level of $\Delta Z_x >$ > 3000 g on the rock-breaking tool, and $\tau = 0.415$ and $l_{dr} \approx$ ≈ 1.7 m providing $\Delta Z_x > 1500$ g. In the absence of adjustment of the backup pressure, the length of the drilling rig should be 2 m. With an increase in the drilling depth and the change in τ from 0.12 to 0.475, the hydraulic vibrator provides the level of values on the drilling tool equal $\Delta Z_x \approx 2200 \div 1000$ g.

Conclusions. Based on the analysis of the results of experimental and theoretical research studies on the dynamic interaction of longitudinal oscillations of the drilling rigs rock-breaking tool with a rock, made in this work, it was established that:

- in the flow part of the hydraulic vibrator liquid medium oscillations arising from the collapse of the cavitation cavity cause longitudinal vibrations of the drilling rigs construction;
- despite the complexity of the physical processes occurring in the cavitational hydraulic vibrator, the mathematical model of the "drilling rig with hydraulic vibrator – rock" system, which takes into account the dynamic properties of the rock and its interaction with the rock-breaking tool, allows obtaining the satisfactory agreement between the calculated and experimental parameters of the fluid pressure and vibration accelerations oscillations in the cross section of rock-breaking tool;
- for the given design of the hydraulic vibrator, the rational regimes of its operation (according to the peak-to-peak value of vibration accelerations dependence on the cavitation parameter) and the length of the drilling rig (according to the distribution of the peak-to-peak values of vibration accelerations along the axial length of the drilling tool) are determined;
- the presented mathematical model of the interaction of the drilling rig with the rock allows establishing the rational regime of vibrational impact of the rock-breaking tool at the design stage.

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Результати випробувань і моделювання системи «буровий снаряд з гідровібратором – гірська порода»

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Перспективним пристроєм, що підвищує ефективність буріння свердловин у міцних і більше від міцних породах, є буровий снаряд із кавітаційним гідровібратором. У ньому, унаслідок періодичного зростання, відриву та схлопування кавітаційних порожнин, реалізуються ударні коливання тиску бурового розчину. Вони трансформуються в поздовжні вібрації породоруйнівного інструменту з частотами 1–20 кГц і значеннями віброприскорень від 500 до 3200 g. При багаторазовому впливі силових імпульсів породоруйнівного інструменту руйнування гірської породи приймає втомний характер. Унаслідок резонансних процесів у системі «буровий снаряд із гідровібратором – гірська порода» й розвитку в породі мережі мікротріщин порушення сплошности гірничого масиву відбувається за напружень менших межі міцності породи. Це призводить до підвищення швидкості буріння, зносостійкості бурового інструменту, поліпшення стабілізації та стійкості функціонування бурової колони

Мета. Визначення поздовжніх віброприскорень бурового інструменту при його контакті із породою, що руйнується, з урахуванням сил, що діють в осьовому напрямку на конструкцію бурового снаряда.

Методика. Заснована на експериментальному й теоретичному дослідженні динамічної взаємодії поздовжніх коливань породоруйнівного інструменту бурового снаряда з гірською породою.

Результати. Представлені у вигляді розрахункових залежностей розмахів коливань тиску рідини та віброприскорень породоруйнівного інструменту від значення параметра кавітації та їх зіставлення з експериментальними даними.

Наукова новизна. Встановлено, що:

- урахування контакту бурового інструменту з руйнованою породою і сил, що діють в осьовому напрямі на конструкцію бурового снаряда, в математичній моделі подовжніх коливань бурового снаряда дозволяє отримати задовільне узгодження розрахункових та експериментальних параметрів коливань тисків рідини і віброприскорень в перетині породоруйнівного інструменту;

- для наведеної конструкції гідровібратора визначені раціональні режими його роботи (по залежності розмаху віброприскорень від параметра кавітації) і довжина бурового снаряди (з розподілу розмахів віброприскорень по осьовій довжині бурового снаряда).

Практична значимість. Полягає в тому, що математична модель системи «буровий снаряд – гірська порода» дозволяє на стадії проектування встановити раціональний режим роботи кавітаційного гідровібратора для реалізації достатніх рівнів віброприскорення на породоруйнівному інструменті.

Ключові слова: *буровий снаряд, кавітаційний гідровібратор, породоруйнівний інструмент, віброприскорення, математичне моделювання*

Результаты испытаний и моделирования системы «буровой снаряд с гидровибратором – горная порода»

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Перспективным устройством, повышающим эффективность бурения скважин в крепких и в сверхкрепких породах, является буровой снаряд с кавитационным гидровибратором. В нем, вследствие периодического роста, отрыва и схлопывания кавитационных полостей, реализуются ударные колебания давления бурового раствора. Они трансформируются в продольные вибрации породоразрушающего инструмента с частотами 1–20 кГц и значениями виброускорений от 500 до 3200 g. При многократном воздействии силовых импульсов породоразрушающего инструмента разрушение горной породы принимает усталостный характер. Вследствие резонансных процессов в системе «буровой снаряд с гидровибратором – горная порода» и развития в породе сети микротрещин, нарушение сплошности горного массива происходит при напряжениях, меньших предела прочности породы. Это приводит к повышению скорости бурения, износостойкости бурового инструмента, улучшению стабилизации и устойчивости функционирования буровой колонны.

Цель. Определение продольных виброускорений бурового инструмента при его контакте с разрушаемой породой с учетом сил, действующих в осевом направлении на конструкцию бурового снаряда.

Методика. Основана на экспериментальном и теоретическом исследовании динамического взаимодействия продольных колебаний породоразрушающего инструмента бурового снаряда с горной породой.

Результаты. Представлены в виде расчетных зависимостей размахов колебаний давления жидкости и виброускорений породоразрушающего инструмента от значения параметра кавитации и их сопоставления с экспериментальными данными.

Научная новизна. Установлено, что:

- учет контакта бурового инструмента с разрушаемой породой и сил, действующих в осевом направлении на конструкцию бурового снаряда, в математической модели продольных колебаний бурового снаряда позволяет получить удовлетворительное согласование расчетных и экспериментальных параметров колебаний давления жидкости и виброускорений в сечении породоразрушающего инструмента;
- для приведенной конструкции гидровибратора определены рациональные режимы его работы (по зависимости размаха виброускорений от параметра кавитации) и длина бурового снаряда (по распределению размахов виброускорений по осевой длине бурового снаряда).

Практическая значимость. Состоит в том, что математическая модель системы «буровой снаряд – горная порода» позволяет на стадии проектирования установить рациональный режим работы кавитационного гидровибратора для реализации приемлемых уровней виброускорений на породоразрушающем инструменте.

Ключевые слова: *буровой снаряд, кавитационный гидровибратор, породоразрушающий инструмент, виброускорение, математическое моделирование*

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