Developing a drilling fluid compensator for increasing the technological condition of drilling equipment

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Abstract. The phenomenon of fluctuations in pressure and fluid flow, as well as hydraulic shocks in most cases lead to negative consequences that affect the technical condition and operation of various equipment. The article discusses the causes of pressure fluctuations of the flushing liquid in the drill string and their consequences, and provides a developed compensator for the flushing liquid, which allows to smooth the flow pulsation.

1. Introduction
Due to the increasing requirements for the economic efficiency of the drilling process, it is important and relevant to improve the layout of the bottom of the drill string in order to increase the durability of drilling equipment, reduce the cost of carrying out down-lifting operations and improve the technical and economic indicators of drilling in General. One of the ways to improve drilling efficiency is to reduce the dynamism of the drill tool when drilling wells and thereby increase the mechanical speed of drilling and the durability of the drill tool [1–8].

2. Materials and methods
In solving the problem of hydrodynamics, the basic laws of theoretical mechanics and hydromechanics were used in relation to the accepted technological scheme for installing a compensator in the layout of a drilling tool, as well as empirical methods.

3. Content of the method and evaluation of its effectiveness
Aznakaevsky PBR LLC “Drilling” drilled a large number of wells. Currently, oil drilling is conducted mainly by turbodrills and downhole motors. Direction is drilled with drilling bits with diameter of 393 mm and then the well is being built with casing pipes with a diameter of 324 mm, the conductor is drilled with drilling bits with diameter of 293,3 mm and then the well is being built with casing pipes with a diameter of 215,9 mm.

The following drill pipes are used: drill pipe 127x9, 19 Z-147 TBPN and TBPC, weighted drill pipe 178x90 Z-147, light-alloy drill pipe 147x11 Z-147.

Piston drilling pumps BRN-1 and NBT-600, which are slow-moving, are widely used for drilling wells. They are a source of uneven flow and pressure of the drilling mud, which, in turn, leads to vibrations, alternating loads in the drill string, uneven operation of turbo drills and screw downhole engines, and, therefore, uneven rotation of the bit and drilling of the rock. Hydraulic shocks occur both
above the turbo drill and on any part of the drilling tool. When drilling deep wells, the start and stop of drilling pumps can be accompanied by short-term, sharp increases in pressure in the circulation system, which also negatively affects the operation of the drilling rig. This is evidenced by the periodic operation of safety valves and ruptures in the diaphragms of compensators for drilling pumps.

The «GEOTEST» computerized station allows monitoring a wide range of parameters of the well drilling process.

The purpose of the station “GEOTEST»:
1) Control of the main drilling parameters, such as the axial load on the bit, pressure and flow of the flushing liquid, mechanical drilling speed, etc. Assessment of the situation and prevention of accidents and complications.
2) Automated collection of geological, geochemical and technological information during drilling.
3) Lithological dissection of the section. Isolation of reservoirs and estimation of saturation character.
4) Documentation of the drilling process. Data transfer from the drilling rig.

The pressure sensor of the washing liquid of the GEOTEST station is a strain gauge pressure Converter. Installation of the pressure sensor to the discharge line is carried out through the medium separator of the standard pressure gauge by means of a tee. The pressure sensor allows the continuous measurement of the oscillations of the washing fluid in the process of drilling a well.

**Figure 1. Mounting the flushing liquid pressure sensor**

The results of measurements of drilling parameters for oil well No. 7063 on Kholmovskaya square are presented below. Geological and technical studies were carried out directly in the process of drilling a well in order to solve a set of geological and technological problems aimed at rapid identification of oil-promising reservoir formations in the section of a drilling well, lithological dissection of the well section, and optimization of the drilling mode. The research was conducted in the range of 355-1410 meters. Technical parameters of drilling (r vx – pressure of the flushing liquid, Wd – load on the bit, Vmex – mechanical drilling speed, Vreys – trip drilling speed) of well No. 7063 and the bits used in this case are shown in table 1.

Up to a depth of 1236 meters, a flushing liquid with a density of 1000 was used, then drilling was carried out with a drilling fluid with a density of 1120. The values of the flushing fluid pressure at the inlet (figure 1), the bit load (figure 2), and the sinking speed (figure 3) registered during drilling are shown in Fig. 2 in the intervals: a) 355–570 meters; b) 570–850 meters; c) 850–1120 meters; d) 1120–1410 meters.

Geological description of the sludge from well No. 7063:
- 355–427 m – artinsky tier (anhydrites, gypsum);
- 427-610 m – Upper Carboniferous (weakly known Dolomites, light gray limestones);
developed a flushing fluid compensator [2], which is recommended to be installed to dampen pressure and flow fluctuations in wells drilled with bits up to 215.9 mm in diameter. For wells drilled with larger diameter bits, to solve the problem of smoothing the uneven pressure of the drilling mud, it is recommended to use an upgraded flushing fluid compensator equipped with a housing 1, a

- 610-700 m – Myachkovsky horizon (grey limestone with dolomite interlayers);
- 700-770 m – Podolsky horizon (limestone light gray, gray);
- 770-835 m – Kashirsky horizon (limestones, mudstones);
- 835-880 m – very horizon (mudstones, gray limestones);
- 880-915 m – Bashkir tier (light gray limestone);
- 915-980 m – protvinsky horizon (limestones, Dolomites);
- 980-1160 m – Serpukhovsko-Oka horizon (the Dolomites are light brown);
- 1160-1220 m – Carbonate rocks of the Aleksinsko-Tula horizon (limestones, mudstones, dark gray, black);
- 1220-1410 m – Terrigenous rocks of the Tula-Bobrikov horizon (dark grey mudstones, siltstones, brown sandstones).

Table 1. Technical parameters of drilling and used bits

| Interval of depth, m | Mud Pressure, MPa | Wd, t | Drilling bit Type/Size | ROP, m/h | Run Speed, m/h |
|---------------------|------------------|-------|-----------------------|---------|---------------|
| beginning | end |               |       |                      |         |               |
| 354     | 616   | 100           | 18    | 215.9 T3ГН           | 442     | 29.1          | 15.2          |
| 616     | 792   | 105           | 17    | R-15 215.9           | 1       | 44            | 16.6          |
| 792     | 980   | 90            | 16    | R-15 215.9           | 43      | 20.4          | 9.1           |
| 980     | 1069  | 89            | 10    | R-05 215.9 T3ГНУ     | 19      | 8.9           | 3.7           |
| 1069    | 1081  | 90            | 12    | R-05 215.9 T3ГНУ     | 19      | 4.8           | 1.6           |
| 1081    | 1136  | 95            | 15    | R-05 215.9 T3ГНУ     | 19      | 13.7          | 3.3           |
| 1136    | 1164  | 85            | 20    | R-05 215.9 T3ГНУ     | 49      | 8.8           | 1.9           |
| 1164    | 1236  | 110           | 10    | R-05 215.9 T3ГНУ     | 49      | 5.5           | 3.6           |
| 1236    | 1267  | 88            | 15    | R-05 215.9 T3ГНУ     | 55      | 2.5           | 0.7           |
| 1267    | 1337  | 90            | 19    | R-05 215.9 T3ГНУ     | 55      | 3.1           | 2.1           |
| 1337    | 1357  | 81            | 14    | R203M144             | 1       | 4.9           | 1             |
| 1357    | 1391  | 89            | 13    | R203M120             | 3       | 3             | 1.4           |
| 1391    | 1420  | 92            | 22    | REED/120.7           | 120     | 1.3           | 0.7           |

Analyzing Fig. 2, graph 1 of which represents the change in the pressure of the flushing liquid during drilling, it becomes obvious the amount of unevenness of the pressure of the flushing liquid during drilling. At an average operating pressure of 9 MPa, the difference between the highest and lowest pressure values reaches 5 MPa or more.

During the drilling process, the bit is also a source of pressure fluctuations and vibrations. When drilling wells in the Aznakaevsky PBR, it was noted that on average, when drilling an oil well, 1 diaphragm of the compensator of the drilling pump fails, the pressure in which is set equal to 2/3 of the working pressure. However, when drilling in the Serpukhov-Oka horizon, which has a fractured nature of the rock, causing the collapse of the rock, clamping the turbodrill body and plugging the holes of the bit and jamming it, as a result of the rupture, it is necessary to replace up to 3-4 compensator diaphragms, which causes a simple drilling for more than 1 hour for each burst of the diaphragm. Along with the numerous costs of drilling wells, a company also has to bear the cost of replacing the orifices of compensators for drilling pumps, with the average cost of the diaphragm D-40 4000 rubles.

Based on this, it can be concluded that the diaphragm compensators used in drilling do not allow to properly extinguish pressure fluctuations in the drill string, and, consequently, additional compensators must be installed in the layout.

We have developed a flushing fluid compensator [2], which is recommended to be installed to dampen pressure and flow fluctuations in wells drilled with bits up to 215.9 mm in diameter. For wells drilled with larger diameter bits, to solve the problem of smoothing the uneven pressure of the drilling mud, it is recommended to use an upgraded flushing fluid compensator equipped with a housing 1, a
spring 2, a closed chamber 3 formed by a spring-loaded piston 4 and a partition 5. The closed chamber is connected by channels 6 to the annulus space (Fig. 3). This compensator can be installed both above the bit and on any part of the drilling tool by means of locking threads, which are attached to the compensator body, and adapters.

**Figure 2.** Recorded drilling parameters of well No. 7063

We solved the problem of the dynamics of the mathematical model of this compensator to determine the main dimensions of the upgraded version of the compensator and to determine the
degree of damping of pressure pulsations.

Figure 3. Schematic diagram of the piston compensator stage

The sequence of calculating the compensator is shown below.

Initial data: D, d, d₁, G - weight of the piston; \( P_u = P_u(t) \) – pressure in the upper part of the flow; \( P_c \) - pressure in the annular space (for simplification of calculations, it is assumed constant); C - spring stiffness coefficient.

In the future, the General law of change is adopted \( P_u \).

\[
P_u = A \sin \omega t + B, \tag{1}
\]

where A is the oscillation amplitude; B is the average pressure; \( \omega \) – circular frequency; t – time.

It is necessary to determine the law of pressure change in the flow area located below the piston compensator \( P_0 \).

Let us make a differential equation of the piston movement. Forces acting on the piston (main forces) \( F_u \) – the force of the flow pressure on the upper part of the piston:

\[
F_u = P_u S_p,
\]

where \( S_p = \frac{\pi(D^2-d^2)}{4} \) is the surface area of the piston.

\( F_e \) – the spring’s elastic force, which is determined by the formula:

\[
F_e = c \Delta l,
\]

where \( \Delta l \) is the deformation of the spring; C is the coefficient of stiffness of the spring.

\( F_c \) – the force of pressure on the piston from below (from the chamber under the piston, where the pressure is assumed to be equal to the annulus):

\[
F_c = P_c S_b',
\]

where \( S_b' = \frac{\pi(D^2-d_b^2)}{4} \) is the surface area of the piston pressure from below G – piston gravity; \( m = \frac{g}{g} \)

– weight of the piston

The differential equation of the piston movement will have the form:

\[
\frac{g}{g} \frac{d^2 x}{dt^2} = P_u S_u + G - c \Delta l - P_c S_b'. \tag{2}
\]

Entering symbols \( \frac{c}{m} = k^2; \frac{s_u}{m} = a; \frac{s_b'}{m} = u; D = P_c u + Ba. \)

Solving equation (2), we get:

\[
X(t) = -\frac{A a \omega}{k(k^2-\omega^2)} \sin \omega t - \frac{B}{k^2} \cos \omega t + \frac{A a}{k^2-\omega^2} \sin \omega t + \frac{D}{k^2}. \tag{3}
\]
In this case, the speed of the piston will be:

$$V_p = \frac{dx}{dt} = \frac{-A\omega}{k^2-\omega^2} \cos kt + \frac{D}{k} \sin kt + \frac{Afw}{k^2-\omega^2} \cos \omega t.$$  \hspace{1cm} (4)

To establish the dependency between the average velocities of fluid in different stream sections, select certain amount of liquid and apply the theorem on change of momentum during an infinitely small interval of time dt, the result is the desired equation that determines the pressure of the flushing fluid at the exit of the compensator:

$$P_0 = P_u(t) - \frac{\rho}{S_u} V_p^2 (S_p - S_p').$$  \hspace{1cm} (5)

Where $\rho$ is the fluid density.

Using equation (5), given the geometric parameters of the compensator and knowing the law of change in the pressure of the washing liquid in the section located at the inlet to the compensator, you can determine the pressure of the washing liquid at the outlet of the compensator.

Solving the inverse problem, we determined the optimal size of the developed compensator.

Thus, the unevenness of pressure and fluid flow in the drill string reaches significant values and negatively affects the drilling process as a whole. Therefore, the development of compensators that reduce the uneven pressure of the drilling fluid in the drill string is an urgent task. The compensator developed by us is one of the ways to solve this problem.

4. Conclusion
Despite the presence of the compensator, installed on the discharge line of the mud pump, the pressure fluctuation of drilling fluid in the drill string, emerging from the pump and from the work of the entire drilling tool as a whole, reaches a considerable value. Therefore, the development of compensators that reduce the uneven pressure of the drilling fluid in the drill string is an urgent task. The compensator developed by us is one of the ways to solve this problem.

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