Dynamics control of a drilling tool by installing a downhole hydromechanical compensator of pressure fluctuations of drilling fluid into the bottom hole assembly

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Abstract. The fluctuation processes of the drilling tool and the pressure of the drilling fluid resulted from numerous factors of both downhole and wellhead nature lead to many negative consequences. The article describes the impact of non-uniformity of the pressure of the drilling fluid on the drilling process, provides an analytical study of the developed downhole hydromechanical compensator of pressure fluctuations of the drilling fluid installed into the bottom hole assembly. The authors obtained an analytical dependence of the degree of decrease in the amplitude of the pressure fluctuations of the drilling fluid in the compensator on the number of damping stages installed in it. The article describes the results of pilot tests of the compensator, indicating the reliability of the theoretical provisions and the high efficiency of the compensator.

1. Introduction
With the increasing requirements for the economic efficiency of the drilling process, it is important and urgent to improve the bottom hole assembly to increase the durability of drilling equipment, reduce the costs of tripping operations and increase the technical and economic performance of drilling as a whole. One of the directions of increasing drilling efficiency is to reduce the dynamics of the drilling tool during well drilling and thereby increase the mechanical drilling speed and durability of the drilling tool.

2. Materials and methods
Solving the hydrodynamic task, we used the basic laws of theoretical mechanics and hydromechanics as applied to the adopted technological scheme for installing the compensator into the drilling tool assembly, as well as empirical methods.

3. The contents of the method and evaluation of its effectiveness
The modern mud pumps supply pulsed fluid due to their design features. To reduce feed irregularities, they are made multi-cylinder, and the cranks are positioned at an angle to each other: in double-cylinder double-acting pumps the angle is 90° and in three-cylinder single-acting pumps the angle is 120°. A further increase in the number of cylinders does not lead to a significant reduction in feed
non-uniformity, while it complicates the design of the pumps.

The non-uniformity of the pump supply depends on the number of cylinders, the principle of operation, the angle of the crank displacement, the operation of the valve mechanism, etc. Figures 1 and 2 graphically show the flow of a double-cylinder double-acting pump and a three-cylinder single-acting pump.

![Figure 1. Supply work of a double-cylinder double-acting pump](image1)

**Figure 1.** Supply work of a double-cylinder double-acting pump: $Q$ - pump supply; $Q_{\text{max}}$ - maximum pump flow; $Q_{\text{min}}$ - minimum pump flow; $Q_{\text{av}}$ - average pump flow; $\phi$ is the rotation angle of the crank.

![Figure 2. Supply work of a three-cylinder single-acting pump](image2)

**Figure 2.** Supply work of a three-cylinder single-acting pump: $Q$ - pump flow; $Q_{\text{max}}$ - maximum pump flow; $Q_{\text{min}}$ - minimum pump flow; $Q_{\text{av}}$ - average pump flow; $\phi$ is the rotation angle of the crank.

In some cases, drilling conditions require the simultaneous use of two mud pumps. It can lead to the appearance of a pressure beating that occurs when two periodic fluctuations fold, for example, harmonic fluctuations with the same amplitudes and slightly different frequencies. The difference in the tension of the V-belt transmission connecting the electric motors to the pumps, as well as the relative slippage on the pulleys can explain the difference in the frequencies of the pressure fluctuations generated by the mud pumps. As a result, at the moments when these fluctuations occur sinphasically, the total amplitude will be maximum, and at the moment when they are in antiphase, they mutually cancel out.
The non-uniformity of the pressure of the drilling fluid while drilling leads to increased wear of the drilling equipment, a decrease in the motor resource of downhole motors, longitudinal and torsional vibrations of the drill string, as well as many negative consequences in the well [1-6]. It is important to note that due to forced tool fluctuations, up to 25-30% of the total power developed by the downhole motor is lost. Energy commensurate with the energy used to destroy the rock face can be spent only on the vibration of the drill collar, even without considering the friction forces. With an increase in the coefficient of dynamism, the longitudinal fluctuations of the bit and the drill string increase accordingly. It can result in short-term detachments of the bit from the bottom, and the bit can collectively be hanging above the bottom up to 50-60% of the total drilling time. Essentially, a reduction in the contact time of the bit with the bottom leads to a decrease in the time of rock destruction and results in a decrease in the mechanical drilling speed.

The pneumatic compensators installed on the flow line of the mud pumps do not adequately damp the fluid pressure fluctuations. The work [5] is one of the works testifying to the low efficiency of the currently used means of damping pressure fluctuations and flow rate of the flushing fluid. It presents the results of experimental studies conducted by the authors in the Bukhara Drilling Administration, located in the Republic of Uzbekistan. We measured the amplitude-frequency characteristics of forced pressure and flow fluctuations obtained under various operating modes of the UNV-600A mud pump. We found that the stationary pump operating mode and an average pressure of 5 MPa results in the impulse of pressure fluctuations in the hydraulic system with a frequency of 18 Hz and an amplitude of 2 MPa.

The study of the influence of pressure fluctuations and drilling fluid flow on the downhole equipment performance revealed the need to install a downhole pressure fluctuation compensator in the BHA. For this purpose, we have developed a downhole hydromechanical compensator, and give its description below.

Figure 3 shows a structural diagram of a multi-stage hydromechanical flushing fluid compensator, consisting of a housing 1 with partitions 2, 3, 4 installed inside it, forming closed chambers with pistons 5, 6, 7 connected by channels 8, 9, 10 with annular space. The installed bushings 11, 12, 13 allows limiting the stroke of the pistons. Springs 14 were installed between the pistons and baffles. Parts in the housing are installed with a sub 15. The housing is equipped with connecting threads 16 and 17. We provide seals 18 to prevent overflow between the pistons and baffles, and the seal 19 to prevent overflow between the body and baffles.

The pulsating fluid enters the compensator, presses on the pistons 5, 6, 7 and thereby compresses the spring in the sub-piston space connected to the annulus through the channels 8, 9, 10. Thereby, the amplitude of the fluctuations in the pressure of the flushing fluid in the cavity of the drilling tool decreases.

Table 1 presents the technical characteristics of the developed hydromechanical pressure compensator for drilling wells with bits with a diameter of 215.9 mm.

Based on the selected model of fluid flow interacting with the piston of a hydromechanical compensator, we performed an analytical solution of the hydrodynamic problem of determining the change in pressure and velocity of a fluid moving through the stages of the compensator for unsteady fluid flow, i.e. when the pressure \( P_0 \) and speed \( V_0 \) of the fluid in the pipe change over time:

\[
P_0 = P_0(t); \quad V_0 = V_0(t).
\]

We conducted pilot field tests to check the performance of the prototype downhole compensator in real drilling conditions. We conducted the study at well No. 224 of the Yuzhno-Izmailovsky field of the Kutlumbebekovsky district of the Orenburg region drilled by LLC MUN-TECHNOLOGY. The drilling was carried out by an ARB-100 drilling rig with a BRN-1 mud pump.

The the drilling tool assembly consists of:
- in 28-165 m, bit 295.3 SZ-GV, KS 293, D5-172, TsS 292, UBT 178 - 18 m, hydromechanical pressure compensator, UBT 178-80 m, SBT-114 * 9.19.
- in 165-741 m, bit 215.9 TD44, KS-214, D5-172, TsS 213, UBT 178-18 m, hydromechanical pressure compensator, UBT 178-80 m, SBT-114 * 9.19.
Figure 3. The structural scheme of the hydromechanical compensator: 1 - housing; 2, 3, 4 - partitions 5, 6, 7, 8, 9, 10 - channels; 11, 12, 13 - bushings; 14 - springs; 15 - sub; 16, 17 - connecting threads; 18, 19 - seals.

Table 1. Technical characteristic of hydromechanical pressure compensator

| Parameters of hydromechanical pressure compensator | For assembly with a 215.9 mm bit |
|-----------------------------------------------|-------------------------------|
| Outer diameter, mm                           | 178                           |
| Overall length, mm                           | 914                           |
| Stages number                                | 3                             |
| Piston diameter, mm                          | 140                           |
| Piston bore diameter, mm                     | 80                            |
| Connecting threads of the nipple and coupling| Z-147                         |
| The diameter of the channels in communication with the annulus, mm | 10 |
| Spring type                                  | Screw cylindrical            |
| Pressure drop, MPa                           | 0.20–0.32                     |

In the process of drilling the well, we periodically measured the fluctuations in the pressure of the flushing fluid with a pressure transducer measuring PDI-01-02 mounted on a high-pressure manifold.

As a result of the measurements, we obtained graphs of pressure changes in the circulation system of the drilling rig during drilling. Figure 4 presents some of them.

The upper part shows a graph of pressure changes during drilling without a compensator at an average pressure of 3.5–3.7 MPa. The graph shows that the amplitude of the pressure fluctuations reaches about 1.8 MPa. The bottom of the slide presents a graph of pressure changes when a hydromechanical compensator is installed in the drilling tool assembly. The graph shows that at an
average pressure of 3.3 MPa, the amplitude range of the pressure fluctuations reaches 1–1.2 MPa.

We should also note that due to a more even bit working time, we obtained an increase in the mechanical drilling speed of 18%, unlike similar drilling without the use of a hydromechanical pressure compensator.

![Graphs of pressure changes during drilling without a downhole hydromechanical compensator (a) and with a compensator (b).](image)

4. Conclusion

Thus, despite the presence of regular pneumatic compensators for drilling pumps, pressure fluctuations of the drilling fluid in the drill string reach significant values and lead to various negative processes.
The developed downhole compensator made it possible to obtain a significant decrease in the amplitude of pressure fluctuations during the pilot tests, as well as an increase in the mechanical drilling speed that undoubtedly indicates a high efficiency of its operation.

References

[1] Minnivaleev T N 2018 Efficiency determination of amplitude decay of pressure fluctuation of circulating fluid with the help of a multi-stage piston-type downhole compensator Advances in Engineering Research (AER) (International conference "Actual issues of mechanical engineering" (AIME 2018)) 157 397-400 DOI: 10.2991/aime-18.2018.76

[2] Minnivaleev T N, Arslanov I G, Yagafarova K N 2018 Graphene aerogel is modern and promising material IOP Conference Series: Earth and Environmental Science (IPDME 2018 – International Conference on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 194(4) 1-5 DOI: 10.1088/1755-1315/194/4/042014

[3] Mukhametshin V Sh, Kotenev Yu A and Sultanov Sh Kh 2018 Assessment of the Need to Stimulate the Development of Hard-to-Recover Reserves in Carbonate Reservoirs IOP Conference Series: Earth and Environmental Science (IPDME 2018 – International Conference on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 194(8) 1-4 DOI: 10.1088/1755-1315/194/8/082027

[4] Batalov S A, Andreev V E, Lobankov V M and Mukhametshin V Sh 2019 Numerical simulation of oil formation with regulated disturbances. Oil recovery quality simulation Journal of Physics: Conference Series (ITBI 2019 – International Conference "Information Technologies in Business and Industry") 1333(3) 1-6 DOI: 10.1088/1742-6596/1333/3/032006

[5] Mukhametshin V V 2018 Bottomhole formation zone treatment process modelling with the use geological and geophysical information IOP Conference Series: Earth and Environmental Science (IPDME 2018 – International Conference on Innovations and Prospects of Development of Mining Machinery and Electrical Engineering) 194(2) 1-5 DOI: 10.1088/1755-1315/194/2/022024

[6] Kuleshova L S, Mukhametshin V V and Safiullina A R 2019 Applying information technologies in identifying the features of deposit identification under conditions of different oil-and gas provinces Journal of Physics: Conference Series (ITBI 2019 – International Conference "Information Technologies in Business and Industry") 1333(7) 1-5 DOI: 10.1088/1742-6596/1333/7/072012