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Research Article

Design and hydraulic modeling of pulse grinding bits for horizontal wells☆

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Abstract

If cuttings carrying performance is poor and cuttings removal is not in time during the drilling of horizontal wells, drilling cuttings will accumulate in the lower sections, leading to backing pressure, BHA binding and even drill pipe sticking. In this paper, a new type of Helmholtz pulse grinding bits suitable for horizontal wells was designed based on the theory of Helmholtz oscillation chamber to generate pulse, jet pump and high pressure jet after the formation of cuttings beds was analyzed. In this type of bit, a high-speed pulse jet is used to assist rock breaking, a reverse jet is used to remove the cuttings at the bottom of the bit under negative pressure, and its inner grinding structure is used to reduce the particle size of cuttings. By using this bit, efficient cuttings removal and rock breaking will be both realized, the chip hold-down effect will be reduced and the cuttings beds in a horizontal well will be also removed. Then, the hydraulic models were established for a pulse generation device, an efficient rock breaking device and a reverse swabbing device, respectively. It is shown from the simulation results that the optimal resonance flowrate increases with the increase of the diameters of an inlet chamber and a feedback chamber and with the decrease of the diameter of a resonance chamber, and it is approximately in linear relationship with each factor. The optimal flowrate ratio of the reverse swabbing device increases first and then decreases with the increase of dimensionless flowrate ratio, and decreases with the increase of dimensionless area ratio. It is indicated from example analysis that the inherent frequency of Helmholtz oscillation chamber is 24.00 Hz, the optimal oscillation flowrate is 23.92 L/s and the optimal flowrate ratio is 0.59. Based on case studies, the accuracy of hydraulic models is verified. It is concluded that this new type of bits provides a new solution to the accumulation of cuttings beds.

Keywords: Horizontal well; Pulse grinding bit; Helmholtz oscillation chamber; Pulse jet; Reverse jet; Optimal resonance flow rate; Optimal flowrate ratio

1. Introduction

With the rapid development of global unconventional oil and gas exploration and development, highly-deviated wells and horizontal wells are increasingly applied widely in order to further improve the efficiency of oil and gas exploration and development. However, if the cuttings carrying performance is poor and the cuttings removal is not in time during the drilling, drilling cuttings usually accumulate in the low side in the migration process and form cuttings bed, which restricts the drilling rate and drilling efficiency and even causes such drilling complications as pump suffocation and drill pipe sticking. Conventional solutions to the above mentioned problems include frequent "short tripping", drilling speed improvement, and displacement increase. Although these solutions have some effects, they cannot fundamentally eliminate the cuttings beds that may appear at any time during the drilling [1].

Due to gravity, the cuttings settle on the low side of wellbore in the process of the wellbore flow and form cuttings bed at the section with a large well deviation [2]. Affected by the drag, lift and buoyancy of fluid, cuttings roll on the surface of the cuttings bed or are lifted to the upper fluid in the migration process [3–5]. Based on the theories about cuttings migration, some scholars have established the basic cuttings migration

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models for horizontal wells, taking into consideration of the thickness of cuttings bed and particle size of cuttings [6] and the time−lapse model for cuttings migration. The corresponding basic model for cuttings migration has also been gradually improved and developed. For example, the average cutting migration velocity has been taken into account in the analysis of the equivalent slip velocity [7], and the empirical formula for cuttings migration in the time−lapse model has been corrected [8]. The experimental study of cuttings migration shows that wellbore curvature, drilling fluid velocity and rheological properties of drilling fluid have a great influence on cuttings rolling and suspension mechanism [9], and turbulent fluid is an effective cuttings migration medium [10]. There are many ways to remove the cuttings beds [11], including by enhancing hydraulic parameters [12], the drill string rotation [13,14] and the application of the improved jet mill to the gas drilling of horizontal wells. Based on the cuttings comminution theory, the jet grinding bit can effectively remove the cuttings beds in the horizontal well [15,16].

However, the relevant theoretical and experimental studies are based on steady-state fluids, and there is little research on pulse fluids. Compared with the conventional steady-state fluid, the pulse jet can greatly improve rock breaking and cuttings removal efficiency with its asymmetric and non-uniform cutting of rocks [17]. Relevant numerical simulation and experimental researches also prove that the pulsed jet drilling technology can improve the development effect of oilfield, while improving the drilling efficiency [18]. In addition, the design of jet drilling bit is only restricted to gas drilling, and there has been no relevant research on conventional drilling fluid circulation drilling.

In view of this, a new type of Helmholtz pulse grinding bit was designed based on the Helmholtz oscillation chamber [19], jet pump and water jet theory. In this type of bit, Helmholtz oscillation chamber is adopted to form a large-scale vortex ring structure and generate pulsed jet, so as to assist in rock breaking and cuttings clearing; a negative pressure is resulted in the swabbing chamber by the high-velocity reverse jet, and then the cuttings at the bottom of the bit are swabbed to reduce the chip hold-down effect; and the cuttings particle size is reduced depending on the high pressure force of internal grinding, to facilitate cuttings carrying. The design can be applied not only to the gas drilling in horizontal wells, but also to the conventional drilling with drilling fluid. Through theoretical calculation, case analysis and parameter study, it can be concluded that the new Helmholtz pulse grinding bit can effectively remove the cuttings bed.

2. A Helmholtz pulse grinding bit

2.1. Structure

The Helmholtz pulse grinding bit consists of a Helmholtz oscillation chamber, a lower jet channel, a swabbing chamber, a reverse high-speed flow channel, a mixing chamber, an accelerating chamber, an internal grinding chamber, an internal grinding machine and a diffusion chamber. The Helmholtz oscillation chamber is composed of an inlet chamber, a resonance chamber, a feedback chamber and a diverging section. Different from the conventional PDC bit, the Helmholtz pulse grinding bit consists of a pulse generation device, a high-efficiency rock breaking device and a negative-pressure swabbing device. There is no chip space in the structure. Instead, the cuttings are discharged through circulation in swabbing chamber − mixing chamber − accelerating chamber − internal grinding chamber − diffusion chamber. Its structure and flow channel are shown in Fig. 1, and the relevant structural parameters are shown in Table 1.

2.2. Working principle

As shown in Fig. 1, the steady-state drilling fluid forms a high-velocity jet flow through the inlet chamber; in the resonance chamber, the unstable shear layer of the jet flow generates a pressure perturbation wave; in the feedback chamber, the jet flow produces a pressure transient and reflects upstream through the contraction section; and the pressure transient upward and the pressure perturbation wave produced by the unstable shear layer interfere with each other in the resonance chamber, forming a large-scale vortex ring structure. Under the action of large-scale vortex ring structure, steady-state flow is transformed into pulse jet. The resulted pulse jet flows through the diverging section to the lower jet channel and the reverse high-speed flow channel, respectively. The asymmetric and non-uniform jet produced by downward pulse jet assist in the high-efficiency rock breaking, agitation and cuttings removal. The upstream pulse jet flows through the reverse high-speed flow channel, and forms negative pressure in the swabbing chamber by virtue of its high velocity. Under the action of negative pressure, cuttings are pumped into the mixing chamber. In the mixing chamber, cuttings and reverse jets form two-phase high-speed turbulence, and flows through the throat into the accelerating chamber. In the accelerating chamber, due to the effect of the viscous force of the drilling fluid, the cuttings move at a high-

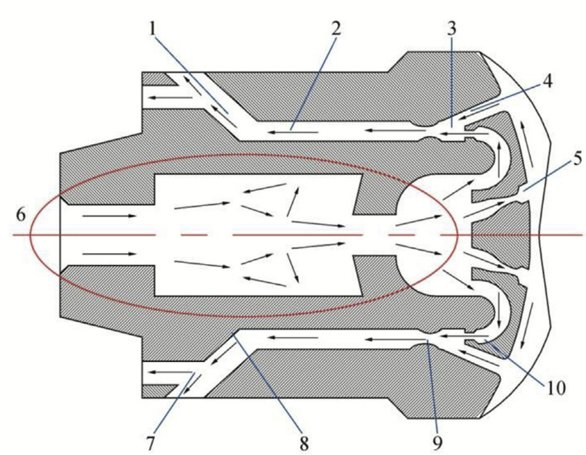

Fig. 1. Schematic diagram of a Helmholtz pulse grinding bit.
Note: 1. Internal grinding chamber; 2. Accelerating chamber; 3. Mixing chamber; 4. Swabbing chamber; 5. Lower jet channel; 6. Helmholtz oscillation chamber; 7. Diffusion chamber; 8. Internal grinding machine; 9. Throat; 10. Reverse high-speed flow channel.