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Paper

PULSED JET TO IMPROVE RATE OF PENETRATION IN DRILLING DEEP WELL

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ABSTRACT

Improving the rate of penetration in deep well is long-term problems for drilling industry. Pulsed jet drilling which has been proved in field is a cost-effective way to improve the rate of penetration. An adjustable frequency pulsed jet generating tool was developed in this paper. The main parts of the adjustable frequency pulsed jet generating tool include turbine, valves, and a resonance pulse chamber. Rotary valve is driven by the turbine. Rotation of the rotary valve causes the state of drilling fluid flow from the continuous to the periodic. So, the periodic flow has frequency and amplitude. In order to obtain higher amplitude, a resonance pulse chamber was used to amplify the amplitude of the periodic drilling fluid flow. The pulsed jet is formed when the periodic drilling fluid flow is issued from the nozzles of the bits. The frequency of the pulsed jet can be easily adjusted by changing the parameters of the rotary valves. In this paper the working principle of the adjustable frequency pulsed jet generating tool was analyzed. The adjustable frequency pulsed jet generating tools have been tested in several wells. The field test results show that the rates of penetration were improved by 21.31%-59.17% and the tool can meet the operation requirements. Adjustable frequency pulsed jet generating tool as an effective approach to improve rate of penetration (ROP) has great application potential in deep well drilling.

1. INTRODUCTION

Drill engineering use a series of tools and techniques to dig a channel to the underground. Drilling technology is mainly used for oil, gas, geothermal, groundwater, and other resource extraction, which is the most important application of the drilling engineering, the proportion of over 98%. With the increase of drilling depth and the difficulty, some new requirements for drilling technology are also proposed. For deep, ultra-deep well, the main difficulties in drilling engineering are low rate of penetration (ROP), long drilling cycle and high cost. Improving bit breaking rock efficiency, increasing ROP and shorten the drilling cycle is a pursuit goal of drilling technology.

Energy required for broken rock comes from the surface, part of the energy through the drilling fluid, drill pipe is passed to the lower part of the drill bit. During the last few decades, a number of techniques used to improve the efficiency of the drill bit rock breaking technology have been developed; the pulse jet drilling technology was one of them. The pulse jet drilling technology can convert a continuous flow drilling fluid to intermittent flow with a certain frequency. After conversion, the exit velocity in bit nozzle was increased substantially. Increasing jet velocity brings the efficiency of jet impingement, and enhanced the efficiency of drilling mud. The pulse jet effect change the cuttings bed distribution in the bottonhole, improve the cuttings upward velocity in the bottom, and avoid the debris of repeated broken. Bottomhole pressure was reduced periodically by the effect of pulsed jet, which decreases the bottomhole rock "pressure hold effect." Hence, with these three effects, the pulse-jet technology can effectively improve the drilling ROP.

Pulse jet drilling technology is widely used to enhance drilling speed, and lots satisfactory results were obtained. Traditional pulse jet drilling technology is installed a pulsed nozzles on the drill bit. Due to bit size, the amplitude and frequency of the pulse jet was limited, which can be adjusted in a narrow ranges. The pulse jet frequency is changes only with the flowrate, resulting in failure to maximize the role of the pulse jet drilling technology. With the increase of well depth, to play greater extent the performance of the pulse jet, pulse jet technology needs to make an appropriate adjustment in frequency and amplitude based on the to be drilled strata properties.

A frequency adjustable pulsed jet generating tool is introduced in this paper. The control valve is driven by a turbine; the rotational valve block will convert the continuous flow of drilling fluid converted into pulse jet flow. To obtain higher amplitude, a pulse resonant cavity was used to amplify the amplitude of the pulsed drilling mud flow. Tool frequency can be adjusted by changing the structure and the parameters of the control valve. The mechanism of frequency adjustable pulsed jet generating tools was analyzed. The field application results show that the adjustable frequency pulse tool can effectively improve the drilling rate of 21.31%-59.17%. Pulsed jet as an effective technology to improve the drilling ROP technology has broad application prospects in deep drilling.

2. WORKING PRINCIPLE OF ADJUSTABLE FREQUENCY PULSE GENERATING TOOL

Adjustable frequency pulsed jet generating tool diagram is shown in Figure 1, including the body shell, the turbine power systems, pulse modulation system and the pulse resonant system. The upper part of body shell is used to connect the drill collar and the lower part directly to drill bit. The role of the turbine system is changing part of the drilling fluid kinetic energy into rotary mechanical energy. Pulse modulation system is set valves which includes rotary valve blocks and the static valve plate. Continuous flow is conversed into pulsed jet by the periodic sealing between the rotary valve blocks and the flow channels in the static valve plate. So, the periodic flow has frequency and amplitude. In order to obtain higher amplitude, a resonance pulse chamber is used to amplify the amplitude of the periodic drilling fluid flow without frequency changing.

Drilling fluid pass the turbine system, drilling fluid impacts turbine blades and guides the drilling fluid flow change direction and drives shaft rotation. Pulse modulation system consists of the rotary valve blocks and the static valve plate (Figure 2). Static valve plate with drilling fluid flow channel is fixed in the body cell. In the process of rotary valve blocks rotation, when the seal blocks coincide with the flow channels in the static valve plate, seals between the seal blocks and flow channels are formed, the drilling fluid flow path is cut off completely (Figure 3), resulting in pressure increase transient; with the rotation, seals between the rotary valve blocks and flow holes are disappearing (Figure 2), drilling fluid through the flow channel to continue the downward movement, so that the pressure drops. In the process of sealing block rotation, the rotation cycle of the seal is formed between the rotary valve blocks with static valve plate channels, which change the original continuous flow of drilling fluid into a periodic pulse fluid.

Figure 4 is pressure oscillation curve of drilling mud flow. “3” marked in the pressure curve wave crest indicates that the flow channels are closed, the position of the rotary valve blocks and the flow channels is shown in Figure 3. Due to the flow channels close, the pressure increase sharply. As the valve blocks rotating, the flow channels were opened, the pressure drop quickly. “2” marked in the pressure curve wave hollow indicates that the flow channels are open, the position of the rotary valve blocks and the flow channels is shown in Figure 2. The close and open of the flow channels result in a periodic pulse flow and pressure oscillation.

The frequency adjustments of the tool mainly rely on the seal times between the rotary valve blocks and the flow channels in static valve. As shown in Figure 2 and Figure 3, rotary valve blocks and static valve form twice seals for a turbine revolution. Therefore, the pulse frequency is 2 times of the turbine rotation period. Typically, the numbers of valve blocks and the flow channels in static valve plate are equal. In this case, the pulse frequency increase with the valve blocks increase, pulse amplitude trend is opposite, reduce as the increase with the valve blocks.

Pulse amplification system is a pulse amplification cavity to amplify the pressure amplitude for pulsed drilling fluid flow. Pulse amplitude is further enlarged in the case of the same frequency. The natural frequency of the pulse amplification chamber is not the same with the frequency of upstream flow.

3. FIELD TEST AND RESULTS ANALYSIS

3.1 H-13A

H13-A well is located in Xinjiang Tarim River flood plain. H13-A well was development wells, vertical wells, with 6845m design depth. Using three open-well structure: first open 406.4mm drill bit to 1500m, 273.05mm casing down to 1500m; second open 241.3mm drill bit to 6627m, 200.03mm casing down to 6625m; third open 171.5mm drill bit to 6845m, openhole completions. Lower section of second open wells drilled Permian, Carboniferous, Devonian, Silurian and Ordovician. These formations with high hardness, high abrasiveness and low drillability lead to low ROP. Because of the high formation temperature cannot be used downhole drill composite drilling, so the wells drilled with pulsed jet tool to improve the ROP after the middle Permian. In 5522m well depth, the tool was set down, and trip out in the depth of 6259m. The BHA as follows:Φ241.3mm PDC bit + φ196.9mm adjustable frequency pulsed jet generating tool + φ196.9mm NMDC×1 + φ241.3mm Spiral centralizer×1 + φ196.9mmDC×3 + φ177.8mmDC ×12 + φ127.0 mm HWDP×15 + φ127.0 mm DP. Drilling with the tool, the drilling parameters as the following: WOB 60-90KN, pump flowrate 30-32L/s, riser pressure20-22.5MPa, mud density 1.23-1.27g/cm3, funnel viscosity 37-45S.

With the tool, the bit drilled 737m. The penetration time was 208.6 hours. The average ROP was 3.53m/h and no bit balling up occurs in the process of drilling. H13-B, H13-C and 13-D were adjacent wells and drilled with the same drilling parameters basically. This pulsed jet field test and well area adjacent well data comparing the results were shown in Table 1. As can be seen from Table 1, H13-B, H13-C and H13-D three wells in this section ROP were 1.75m / h, 2.87m / h and 2.29m / h, the average ROP was 2.30 m / h for the three wells. Compared with adjacent wells, the ROP of H13-A well using a pulsed jet generation tool increased 101.14%, 22.65% and 53.71%. Compared with the adjacent well average, ROP was improved by 59.17%.

3.2 Z15-A Well

Z15-A well was a development wells with 6785m design depth with three open casing programs. The 241.3mm open hole section was 4782m from 1200m to5982. Generally, using downhole motor combination PDC bit can obtain higher ROP in upper and middle part of the 241.3mm open hole. However, due to formation temperature and downhole safety, the downhole motor cannot be used in the lower part of 241.3mm open hole (>5000m depth), so the ROP is low, which ranges 1.2-2m/h. the formation is higher hardness and abrasive mudstone and sandstone. The tool was set down in 5346m depth, and trip out wellbore in 5761m. BHA as follows: φ241.3mmPDC bit + φ196.9mm adjustable frequency pulsed jet generating tool + φ196.9mmNMDC×2 + φ241.3mm Stabilizer×1 + φ196.9mmDC×3+ φ241.3mm stabilizer×1 + φ196.9mmDC×3 +φ177.8mm DC×12 + φ127mmHWDP×15+φ127mmDP. Drilling with the tool, the drilling parameters as the following: WOB 60-90KN, pump flowrate 28- 30L/s, riser pressure19- 21MPa, the drilling fluid density 1.28-1.30g/cm^3.

With the tool, the bit drilled 415m. The average ROP was 2.85m/h. Z15-B and Z15-C were adjacent wells and drilled with the same drilling parameters basically. This pulsed jet test and well area adjacent well data comparing the results were shown in Table 2. As can be seen from Table 2, Z15-B and Z15-C in this section ROP were 2.47m/h and 2.24m/h, the average ROP was 2.36 m/h for the two wells. Compared with adjacent wells, the ROP of Z15-A wells using a pulsed jet generation tool increased 15.38% and 27.23%. Compared with the average of adjacent wells, the ROP was improved by 21.31%.

3.3 Z16-A Well

Z16-A well was a development wells with 7474m design depth with three open casing programs. The 241.3mm open hole section was 4907m from 1200m to 6107. In 241.3mm well lower section, the Silurian strata are fine sandstones and asphaltene powder - fine sandstone and mudstone. ROP was low in this section. The tool was set down in 4715m depth, and trip out wellbore in 5088m. BHA as follows: φ241.3mmPDC bit + φ196.9mm Pulse jet generating tools + φ196.9mmNMDC×2 + φ241.3mm Stabilizer×1 + φ196.9mmDC×3 + φ241.3mm stabilizer×1 + φ196.9mmDC×3 + φ177.8mm DC×12 + φ127mmHWDP×15 + φ127mmDP. Drilling with the tool, the drilling parameters as the following: WOB 60-80KN, pump flowrate 30- 32L/s, riser pressure20- 22MPa, the drilling fluid density 1.28-1.30g/cm^3.

With the tool, the bit drilled 373m. The average ROP was 3.93 m/h. Z16-B and Z16-C were adjacent wells and drilled with the same drilling parameters basically. This pulsed jet test and well area adjacent well data comparing the results were shown in Table 3. As can be seen from Table 3, Z16-B and Z16-C in this section ROP were 2.85m/h and 3.37m/h, the average ROP was 3.11 m/h for the two wells. Compared with adjacent wells, the ROP of Z16-A wells using a pulsed jet generation tool increased 37.89% and 16.62%. Compared with the average of adjacent well, the ROP was improved by 26.4%.

4. CONCLUSION

(1) An adjustable frequency pulsed jet generating tool was developed based on combination of the mechanical force pulse and the self-excited oscillation pulse technology. The tool installed in the upper part of the drill bit and modulated pulsed jet in bit nozzles. Pulsed jet can change the stress state in bottomhole, improve cuttings return speed and jet impact, and ultimately to improve drilling ROP and bit footage.

(2) Three wells field test results showed that: adjustable frequency pulsed jet generating tool can improve the ROP 21.3% -59.17%, drill footage increased by 30% or more. Tool life can meet the demand for on-site drilling operations basically.

(3) Adjustable frequency pulsed jet generating tool with simple structure and high reliability can achieve higher ROP in drilling deep wells. Pulsed jet as an effective technology to improve ROP drilling in deep drilling technology has broad application prospects.

5. REFERENCE

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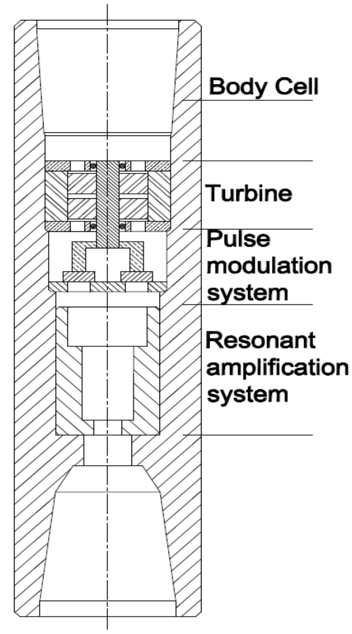

Fig. 1 Schematic of the adjustable frequency pulsed jet generating tool

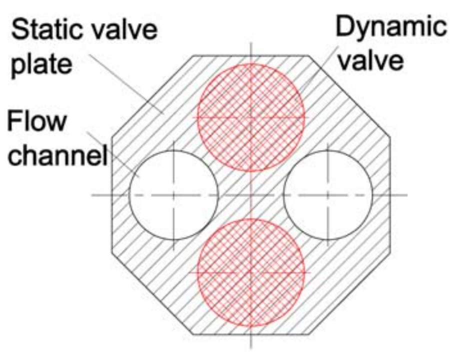

Fig. 2 Schematic of the pulse modulation system

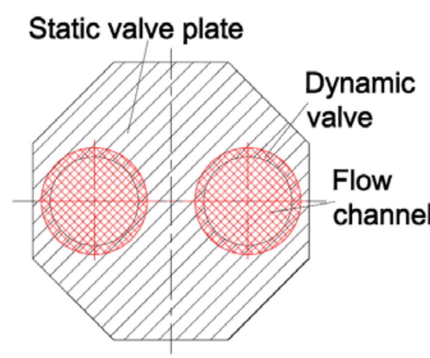

Fig. 3 The seals between the rotary valve bocks and flow channels

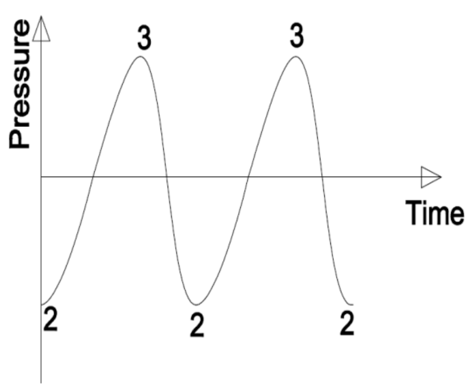

Fig. 4 Pressure amplitude and frequency of pulsed drilling flow

Table 1 **H13-A test results and comparison of the data from offset wells**

Well	Section (m)	Footage (m)	ROP (m/h)	Comparison (%)
H13-A	5522-6259	737.00	3.53	--
H13-B	5539-6269	730.00	1.75	101.14%
H13-C	5538-6259	721.00	2.87	22.65%
H13-D	5501-6260	749.00	2.29	53.71%
Average of offset wells		733.00	2.3	59.17%

Table 2 Z15-A test results and comparison of the data from offset wells

Well	Section (m)	Footage (m)	ROP (m/h)	Comparison (%)
Z15-A	5346-5761	415	2.85	
Z15-B	5363-5667	304	2.47	15.38%
Z15-C	5328-5634	306	2.24	27.23%
Average of offset wells		305	2.36	21.31%

Table 3 Z16-A test results and comparison of the data from offset wells

Well	Section (m)	Footage (m)	ROP (m/h)	Comparison (%)
Z16-A	4715-5088	373	3.93	
Z16-B	4752-5138	388	2.85	37.89
Z16-C	4689-4998	309	3.37	16.62
Average of offset wells		348.5	3.11	26.4