Journal of Petroleum Science and Engineering 146 (2016) 318–325

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

A novel tool to improve the rate of penetration by transferring drilling string vibration energy to hydraulic energy

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ARTICLE INFO

Article history:
Received 5 September 2015
Received in revised form
16 March 2016
Accepted 18 April 2016
Available online 22 April 2016

Keywords:
Drilling
Penetration rate
Drilling string vibration
Ultra-high pressure water jet
Field test

ABSTRACT

The ultra-high pressure water jet assisted mechanical drilling technology is an effective approach to improve the rate of penetration (ROP), however, due to unreasonable design ideas and low reliability of the existing down-hole supercharger, this technology is not applied widely. To make breakthrough of this technology, a new idea of utilizing the drill string vibration energy to modulate ultra-high pressure jet is first proposed, and a novel down-hole supercharger, down-hole drill string absorption & hydraulic supercharging device (DSAHSD), is developed. The DSAHSD combines the advantages of reducing the axial drill string vibration and generating ultra-high pressure jet to effectively assist rock breaking. When the drilling fluid flows through this tool, part of the drilling fluid will be modulated to the ultra-high pressure jet by periodic compression of piston drove by drill string vibration. Because of hydraulic auxiliary rock breaking of the ultra-high pressure jet, the drillability of rock and the ROP will be enhanced. To analyse the feasibility and influence factors of the tool, mathematical model were established, the results show that the tool could produce more than 140 MPa pressure and the outer pressure increases with the increase of weight on bit and rotary speed. Moreover, there is an optimal diameter of ultra-high pressure nozzle to optimal performance of the tool. This tool has been applied to more than 60 wells in four oil fields throughout China. The results indicate that the maximum density of the test drilling fluid is 1.9 g/cm3, the single maximum footage is 1480 m, and the operation time of the tool is more than 200 h. Furthermore, the average ROP was increased by approximately 11–831%. In conclusion, the DSAHSD has the characteristics of a simple structure, has a long lifetime, is able to adapt well with existing drilling equipment, and can provide guarantee for wide application of the ultra-high pressure jet technology in oil fields.

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1. Introduction

Drilling is the key procedure and method to oil and gas exploration and development. A survey (Li et al., 2015) indicates that drilling time takes up to one-third of the well-construction period, almost one-half in a deep well. Therefore, improving ROP is crucial to accelerate process of oil and gas exploration and development in deep formations. Drilling practices shows that the ultra-high pressure jet drilling technology (Maurer, 1980) is a feasible way to enhance ROP in deep wells.

The development of the ultra-high pressure water jet assisted mechanical drilling technology has gone through two stages: the development of surface hydraulic booster and the development of down-hole hydraulic booster. The first phase is in 1970s. In the early 1970s, Maurer et al. (1973) carried out experimental study on the feasibility of high pressure water jet drilling in deep wells, the field tests showed that the down-hole injection pressure increased to 68–105 Mpa could improve ROP 2–3 times. In the mid-1970s, the Exxon Company and other petroleum companies (Rehbinder, 1976) have jointly developed special high-pressure bit test equipment which could produce up to 98 MPa of injection pressure. Through one filed experiment, the ROP was improved 1.4–3.2 times than adjacent wells. In the late-1970s, 30 experiments of the ultra-high pressure jet drilling on roller bit were conducted in soft formations of East Texas by the American reed company. In experiments, the injection pressure was up to 69–138 MPa, and ROP was improved 2–3 times. Although the effect to improve ROP is significant, the equipment and procedure are too complex for surface booster and the effect is significantly affected by the well depth, this way was not widely applied.

The second phase is from 1980s to the present, because the

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http://dx.doi.org/10.1016/j.petrol.2016.04.025
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down-hole hydraulic booster could produce ultra-high pressure jet with a booster installed on the upper part of the bit without changing the surficial drilling technology and equipment, in this phase, petroleum engineers and scientists emphasises on researches of the development of down-hole hydraulic booster. In 1980s, FlowDrill company and Grace drilling company jointly developed two-channel jet drilling auxiliary system, it could increase the ROP 1.4–3.2 times, but the work life was less than 30 h. In 1990s, FlowDrill company and GRI (Veenhuizen, 1995) put forward the research project of jet assisted mechanical drilling together, the tests indicated that the working life of down-hole pumps was less than 40 h, improved ROP 100%. In 2000s, Maurer Engineering Inr company (Cohen, 2005) designed the ultra-high pressure jet drilling system and conducted laboratory and field tests, the ROP increased 1.3–6 times in different formation, and the working life is less than 40 h. Moreover, according to the various modulating methods of ultra-high pressure jet, some researchers have developed several types of down-hole hydraulic supercharging device in China, such as the down-hole hydraulic supercharger (Wang et al., 2002), the centrifugal down-hole supercharger (Sun et al., 2006), the fluidics down-hole boost compressor (Wang et al., 2008), the by passing down-hole supercharger (Cheng et al., 2008), the screw down-hole hydraulic supercharging device (Xu et al., 2010), and the diaphragm pressure converter used in bottom-hole (Ai et al., 2001).

Due to the short working life and the poor reliability, all these tools mentioned above are not applied widely. According to the working principle of these tools, we found that the working power to generate ultra-high pressure jet all comes from the pressure energy carried by the drilling fluid itself. The process of realization is to transfer the energy of most part of the drilling fluid into a small part of the drilling fluid, the problems encountered during the realization and application process as follows: i) the energy conversion structures of all these tools are too complicated and hence the working life and safety cannot be ensured; ii) as the well depth increases, the circulating pressure loss increases and the down-hole hydraulic pressure energy decreases, thus the effect of improving the ROP will be influenced apparently. If other energy in the well bottom can be introduced to modulate the ultra-high pressure jet, it could be a major breakthrough to develop novel down-hole hydraulic supercharging device. Study on drilling string dynamics in vertical wells shows that the drilling string vibrates violently associated wide fluctuation of bit pressure in the drilling. The violent vibration of drilling string contains a great mechanical energy which not only lead to fatigue failure of drilling string and also lower the efficiency of rock breaking. If a gadget which can convert drill string vibration into ultra-high pressure is developed, the ROP can be enhanced and the service life of drill bit and drilling string can be prolonged. Based on this idea, Guan et al. (2012) successfully developed a DSAHSD that combines the advantages of reducing drill string vibration and generating ultra-high pressure jet. And it has effective application in more than 60 wells of many oil fields.

2. Structure and operating principle of DSAHSD

2.1. Structural design

The DSAHSD comprises two portions, the upper portion of the device is a vibration-reduction system, and the lower portion is a supercharging system for drilling fluid. An upper transition joint, a splined shaft and a plunger check valve are jointed together into an integral, the splined shaft engages with the splined sleeve so as to transmit the torque and to allow the splined shaft to move up and down. Moreover, the splined sleeve, a spring case, a transition joint, a piston cylinder, a high pressure channel, a cylinder outer sleeve and a lower joint are jointed together into an integral. The energy generated by drill string vibration can be decomposed into three parts by the vibration-reduction system, the first is used to supercharge portion of the drilling fluid; the second is consumed by compression and reset of the elastic reset device; and the third is for percussion drilling. The supercharging system could convert the first part of the energy into portion drilling fluid for supercharging the drilling fluid to realize rock breaking or auxiliary rock breaking by the ultra-high pressure jet.

2.2. Working principle

The DSAHSD is installed between the bit and drill collar or other drilling tool, when the intensity of the drill string vibration reaches a certain level, the device starts to work. As the intensity of vibration increases, the pressure of the ultra-high pressure jet increases, and with the increase of the vibration frequency increases, the flow of the ultra-high pressure jet increases. During drilling, the drill string sets the upper transition joint, the splined shaft, and the plunger check valve in up-and-down motion together due to the longitudinal vibration of the drill string; meanwhile, the compression and expansion of the spring ensures that the spring case, the piston cylinder etc. will not move up-and-down along with the drill string. When the drill string moves upwards, it drives the splined shaft and the plunger check valve to move upwards relative to the piston cylinder, and negative pressure is generated in the piston cylinder, thus the drilling fluid is sucked therein. When the drill string moves downwards, it drives the splined shaft and the plunger check valve to move downwards, and the drilling fluid in the piston cylinder is compressed and pressurized. The pressurized drilling fluid enters into the high pressure channel and then realizes injection by ultra-high pressure nozzle to assist for breaking rock at the shaft bottom. With the up and down vibration of the drill string during drilling, the process continuously reciprocates. Due to the damping of the spring and the drilling fluid in the piston cylinder, the tool also could reduce the drill string vibration.

According to the working principle of the DSAHSD, it utilizes the drill string vibration energy to modulate ultra-high pressure jet, the power source provided by drilling string vibration that increases with the increase of well depth (Guan and Zhang, 2014; Liu et al., 2008); with no complex reverse mechanism, the life of the gadget is sure, and it realizes the conversion of the drill string

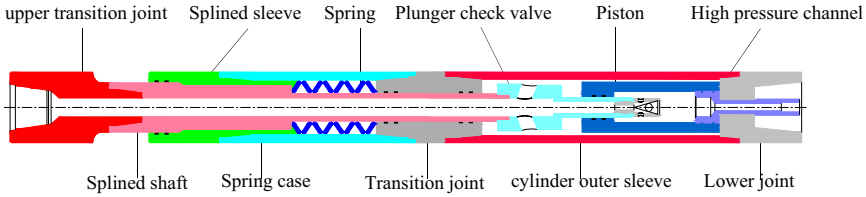

Fig. 1. Structure design of the DSAHSD.

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