Journal of Petroleum Science and Engineering 164 (2018) 320–332

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

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

Method and apparatus for monitoring of downhole dynamic drag and torque of drill-string in horizontal wells

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ARTICLE INFO

Keywords:
Horizontal well
Drill-string
Dynamic drag force
Dynamic torque
Weight-on-bit
Torque-on-bit

ABSTRACT

Monitoring and control downhole drag and torque is a eternal research topic in horizontal drilling technique, but the theory and experience are still in the exploring stage. In this work, an integrated dynamic monitoring method, including a downhole parameters measuring system and a model for calculating the effective weight of drill-string, is proposed to discover the downhole drag and torque. A computational program is developed in the Visual Basic environment. Taking well T2-4-22H1 as an example, the downhole experiment are conducted to obtain downhole weight-on-bit (DWOB) and downhole torque-on-bit (DTOB) by using the developed downhole parameters measuring apparatus (DPMA). The experiment results are utilized for verifying the feasibility and suitability of the present method. The results show that the measured DWOB is significantly lower than the recorded surface weight-on-bit (SWOB) under sliding mode. As a result, the downhole based drag force is obviously higher than that based on surface data. For rotary mode, though the weight-on-bit and drag force do not make significant difference on both surface and downhole, but excessive frictional torque is generated due to drill-string rotating. The main reasons caused the diversity of surface and downhole parameters are discussed. Additionally, based on the measured downhole parameters, the changing rules of friction coefficient under different drilling modes are inversed. The present drag and torque monitoring method can provide a powerful technical support for the safe and high-efficiency drilling of horizontal wells.

1. Introduction

Since the conventional oil and gas resources are gradually exhausting, we have to pay attention to some unconventional oil and gas resources, such as the offshore oil and gas, coal bed gas, tight oil and gas, shale oil and gas (Zou et al., 2015). In order to exploit unconventional oil and gas resources efficiently, more and more horizontal wells, highly-deviated wells and extended reach wells are utilized (Chen, 2011; Ma et al., 2016). The horizontal wells are usually utilized to exploit the low permeability reservoir, due to it is beneficial to economize the area of the well pad, enlarge the drainage area of the reservoir, and conduct the multistage hydraulic-fracturing, consequently, enhanced oil and gas recovery (Chen et al., 2014; Ma et al., 2015, 2016, 2017). The highly-deviated wells and extended reach wells are usually utilized to exploit the beach and offshore oil and gas reservoir, due to it is beneficial to economize the drilling and production platforms, and reduce the exploitation costs (Ma et al., 2015, 2016, 2017). However, directional or horizontal drilling usually brings about some new challenges, and the excessive drag and torque of drill-string is one of the most commonly encountered problems (Liu et al., 2016, 2017; Wang et al., 2017). The excessive drag and torque of drill-string often causes a low rate of penetration (ROP), which also increase the drilling non-productive time (NPT), drilling cycle and costs (Huang et al., 2015; Ma et al., 2016).

There are a large number of causes for excessive drag and torque, including tight hole conditions, sloughing hole, keyseats, differential sticking and dogleg severity (Johancsik et al., 1984). Another reason for slide drilling in high-angle wells is that cuttings removal suffers from the lack of drill-string rotation (Xiang et al., 2014; Wei et al., 2014). In order to mitigate the impact of excessive drag and torque on drilling operation, many theoretical methods were proposed to predict the drag and torque of drill-string under different drilling conditions. These methods provided the theory foundation for optimizing bottom hole assembly (BHA) and adjusting drilling parameters to a great extent. Johancsik et al. (1984) first proposed the soft-string model of a tubular string in oil and

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https://doi.org/10.1016/j.petrol.2018.01.077
Received 8 July 2017; Received in revised form 22 January 2018; Accepted 30 January 2018

gas wells, which considered the tension and gravity of the drill-string in directional wells, as well as the borehole trajectory. Sheppard et al. (1987) took into account the impact of drilling mud properties and improved the soft-string model that was established by Johansick. Thereafter, there has been an outpouring of literature researched in this field (Maidla and Wojtanowicz, 1987; Lesage et al., 1988; Brett et al., 1989). Although these models can meet the requirements of drilling engineering to some extent, there still have great distinctions between calculation results and real one due to the stiffness and motion status of drill-string being neglected. To overcome these disadvantages, Ho (1988) deduced a stiff-string model considering the influence of drill-string stiffness. Li (2008) and Li et al. (2017) proposed an improved model to calculate the drag and torque of horizontal wells through introducing the concept of equivalent friction coefficient. This model has been used extensively in drilling operations of china. Qin et al. (2006) constructed a hybrid model considering the interaction of drill-string and borehole, but this model was very complicated and difficult to apply. Additionally, a large number of researchers have studied the drag and torque of drill-string by finite element method (Zhang et al., 1992; Shuai et al., 1995; Fu et al., 2007; Zhu et al., 2007, 2015). Until now, all kinds of methods and models have been created, but the relative error between the forecasted and real one increases as the complexity of the well types increases. The reasons lie in (Huang et al., 2015; Li et al. 2012, 2017; Mitchell and Samuel, 2009): (1) all the theoretical models were established based on the Coulomb model, which cannot get rid of the dependency on friction coefficient, and (2) friction coefficient and wellbore tortuosity are important factors affecting the drag and torque, but it cannot be measured directly, and (3) it is difficult to quantitatively describe the complex contact status between drill-string and borehole.

Therefore, the main objective of this research is to propose a drag and torque monitoring method for horizontal well, in which the friction coefficient and wellbore tortuosity can be ignored. The key of this method is to measure the downhole parameters, including downhole weight-on-bit (DWOB) and downhole torque-on-bit (DTOB), and calculate the effective weight of drill-string (EWDS). Once these parameters are available, the downhole dynamic drag and torque (DDD&T) can be acquired conveniently. Field applications are carried out to illustrate the feasibility and suitability of the presented method. The influence law of drilling parameters on drag and torque is also systematically discussed for different drilling conditions.

2. Downhole monitoring apparatus while drilling

The Intelligent Drilling Integrated System (IDIS), as an effective measure of solving the above-mentioned issues, has been put forward in recent years based on the logging while drilling (LWD) system and the rotary drilling system. The whole system works in conjunction with surface intelligent system and drilling analysis software, which makes it possible to measure and control drilling parameters in real-time (Tang et al., 2012; Tahmeen et al., 2010; Hu et al., 2014). The state-of-the-art for IDIS at home and abroad is shown in Fig. 1. The drilling engineering parameters measuring system (DEPMS) is a key aspect of IDIS, which can not only evaluate severe drilling conditions at a depth of several thousand meters, but also accurately measure downhole engineering parameters (DEP) while drilling, including DWOB and DTOB (Wang et al., 2010; Ma and Chen, 2015).

Despite the research of DEPMS in China started later, it is in a rapidly developing stage now. To measure DWOB and DTOB accurately, we developed a new drilling parameters measuring apparatus (DPMA) based on the resistive strain measuring technique, as shown in Fig. 2. The strain gauges are pasted on the test spindle and each strain component make up a Wheatstone bridge, which can be used to measure DWOB, DTOB and lateral force. There are two pressure sensors used to measure the internal and external pressure of drill-string. To satisfy the measurement demand of slim hole and routine borehole, two kinds of DPMA with different specifications were designed and produced. Their main technical indicators are listed in Table 1, and parameters in brackets denote slim hole. The appearance of the developed DPMA is in accordance with slick drill collar and it does not affect the structure of BHA and the transmission of MWD signals.

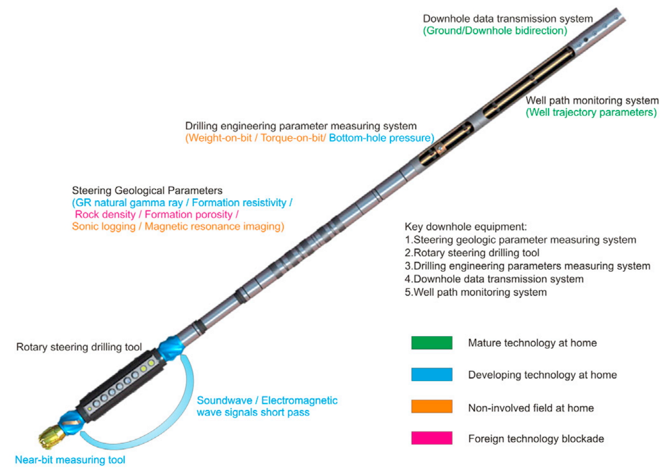

Fig. 1. The state-of-the-art for IDIS at home and abroad.

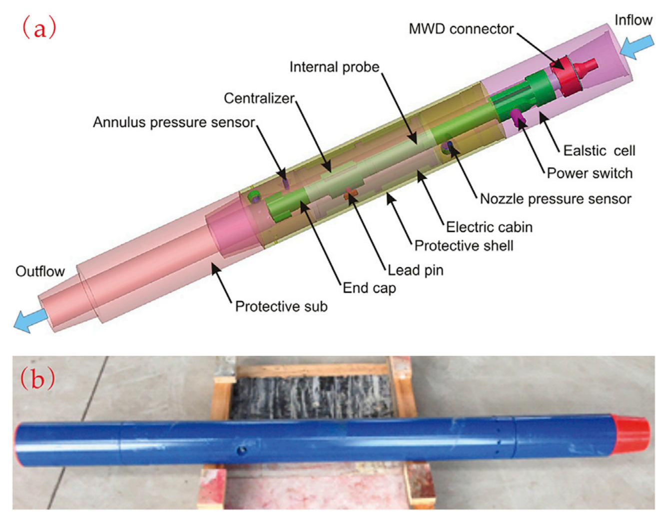

Fig. 2. The developed downhole monitoring apparatus. (a) Schematic diagram; (b) Picture of real products.

Table 1
The technical indicators of downhole monitoring apparatus.

Technical indicators	Value	Technical indicators	Value
Outer diameter, mm	177.8 (120.7)	Maximum working tension, kN	1000 (750)
Length, mm	1656 (1290)	Maximum allowable vibration, m/s^2	200 (200)
Diameters of the bits, mm	215.9 (152.4)	DWOB measurement range, kN	0~250 (0~200)
Working temperature, °C	150 (150)	DTOB measurement range, kN·m	0~10 (0~8)
Working pressure, MPa	140 (100)	Annulus pressure measurement range, MPa	0~60 (0~60)
Operating time, h	150 (150)	Lateral force measurement range, kN	0~50 (0~50)

Remark: There are two kinds of DPMA with different specifications, i.e., slim hole and routine borehole. The parameters listed in the brackets denote to the slim hole.