How Bit Profile and Gauges Affect Well Trajectory

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Summary

The importance of wellbore deviation is well recognized by the drilling industry. An analysis of a drilling system's directional behavior must include the directional characteristics of the drill bit. This paper presents a comprehensive analysis of the directional behavior of polycrystalline diamond compact (PDC) bits, including the effect of bit profile, gauge cutters, and gauge length. Numerical simulations as well as laboratory tests have been carried out to better understand the mechanisms of PDC bit deviation and to evaluate the most important parameters affecting the directional behavior of PDC bits.

The analysis presented in this paper shows that each part of the PDC bit (profile and active and passive gauges) plays a major role in its walking tendency and steerability. A quantitative evaluation of how these factors contribute to well trajectory (inclination and azimuth) is given.

For the first time, a full-scale directional-drilling bench was built to measure the walking tendency and steerability of PDC bits. The results obtained demonstrate that the bit profile, gauge cutters, and gauge length have a significant effect. A 3D theoretical rock-bit interaction model was developed to reproduce the drilling test results.

Introduction

The oil and gas industry relies greatly on directional drilling to develop petroleum reserves in environmentally sensitive areas or in restricted surface areas through an increasing number of multilateral, horizontal, and extended reach wells. Many directional systems can be used to drill and control the deviation of these more complex wells. Depending on well characteristics, one can select a rotary bottomhole assembly (BHA), a steerable mud motor, or, more recently, a rotary steerable system (RSS). Whatever the system used, the drill bit has an influence on the system's directional behavior. This paper defines the contribution of the different PDC bit parts on its directional behavior (steerability and walking tendency) and their impact on well trajectory.

Background

Theory. The directional behavior of a PDC bit is generally characterized by its walk tendency and steerability. The walk tendency, or bit turn, is a concept well known by drillers and a natural phenomenon existing in any rotating cutting drilling heads. From this tendency, Ho[1] introduced the walk angle for PDC bits, the angle measured in a plane perpendicular to the bit axis, between the direction of the side force applied to the bit and in the direction of the lateral displacement of the bit (**Fig. 1**). The walk angle quantifies the intrinsic azimuthal behavior of the PDC bit. When bit lateral displacement is on the left of the side force, the bit has a left tendency. If the displacement is on the right of the side force, the bit has a right tendency. A neutral bit means that the lateral displacement is in the same direction as the side force. According to the surface position (and considering the previous definition), if the bit goes to the left when we are in a building phase, then its tendency is left; if it goes to the right in the same phase, then its tendency is right. However, if the bit is going to the left while dropping, its tendency is right; if it goes to the right, then it has a left tendency. It is worth noting that an intrinsic neutral bit does not necessarily give a zero turn rate, because this depends not only on bit characteristics behavior but also on the BHA behavior and the formation characteristics, mainly anisotropy.

The bit steerability (B_S) corresponds to the ability of a bit to initiate a lateral deviation when submitted to lateral and axial forces. The bit steerability can be defined as the ratio of lateral to axial drillability.

$$B_S = \frac{D_{\mathrm{lat}}}{D_{\mathrm{ax}}} \quad (1)$$

The lateral drillability (D_{lat}) is defined as the lateral displacement per bit revolution over the side force. The axial drillability (D_{ax}) is the axial penetration per bit revolution over the weight on bit (WOB). The B_S (equivalent to the bit anisotropic index[1,2]) is generally in the range of 0.001 to 0.1 for most PDC bits, depending on the cutting profile, gauge cutters, and gauge-pad characteristics, as evaluated here. A bit with a high steerability means a strong propensity for lateral deviation, enabling us to obtain a maximum potential for the build or drop rates. Assuming that the BHA applies a nonzero side force to the bit without bit tilt angle, the bit steerability can be linked to the build or drop rate of well trajectories in the field.

Field and Laboratory Observations. ***Steerability.*** Many studies have been carried out in the laboratory or in-situ to estimate the effect of PDC bits on the build and drop rate of well trajectories. In analyzing the data from Gulf of Thailand wells, Perry[3] reported that the profile and gauge length of PDC bits could affect the build and drop tendencies of BHAs. Pastusek *et al.*[4] conducted some directional tests in the laboratory to study the behavior of antiwhirl PDC bits and noticed that these bits had a lower side-cutting ability than conventional PDC designs. Pastusek *et al.*[4] attributed this difference to the smooth gauge pads used for the antiwhirl bits and concluded that the build rate of antiwhirl bits on steerable systems was lower than on conventional PDC designs.

O'Bryan and Huston[5] studied the effects of gauge length on the build and drop tendencies of PDC bits. In testing two different lengths (88.9 and 152.4 mm), the authors reported that the highest build/drop rate was obtained with the longer gauge. This phenomenon was explained by a higher WOB on the PDC bit with the longer gauge, generating a higher side force on the bit.[5] More recently, Norris *et al.*[6] carried out a study in the laboratory and in-situ to evaluate the bit side-cutting ability. One roller-cone bit and two PDC bits, with various gauge aggressiveness, were tested on Carthage marble in the laboratory. With varying WOB and side force applied on the bit, the authors observed a B_S in the range of 0.04 to 0.4. The lateral drillability of the PDC bit with an aggressive gauge was almost 10 times higher than the one with an unaggressive gauge. However, some irregularities and ledges on the borehole were observed with the most aggressive PDC bit. Furthermore, the roller-cone bit showed a lower side-cutting ability than the two PDC bits. In analyzing field data, the authors noticed a good correlation between the PDC bit side-cutting ability evaluated in the laboratory and the build/drop rate measured in the field.

Walking Tendency. Based on field observations, it is generally accepted that roller-cone bits almost always have a right tendency

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