

PDC Bit Classification According to Steerability

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Summary

With the emergence of rotary steerable systems (RSSs), the technical issue concerning bit design for a specific directional application has reappeared. Today, a bit must be specifically designed for use with a particular directional system: rotary bottomhole assembly (BHA), steerable mud motor, or RSS. The reason is that the bit must have the ability to respond properly and rapidly to a side force applied by the steering system to initiate a deviation. To do so, the bit must have a predetermined steerability compatible with the directional system to provide the optimum dogleg potential.

The new generation of directional-drilling systems differentiates “pointing the bit” from “pushing the bit.” As a consequence, the bit’s directional response is a key factor that operators and directional drillers need to know to make a good adaptation between the bit and the BHA. However, at the moment there is no standard method for classifying bits by steerability and walking tendency.

On the basis of a comprehensive analysis of the directional behavior of polycrystalline diamond compact (PDC) bits (numerical simulation and pilot and field tests), a simple methodology has been developed that defines and evaluates their steerability and walking tendency. This methodology is used to classify the PDC bits defined with their IADC bit profile codes.

Because PDC bit steerability is mainly a function of the bit profile, the gauge cutters, and the gauge pad, some design recommendations are given concerning these three parts. For each IADC bit profile code, the bit steerability and walking tendency are estimated through some formulas linking only the heights and lengths of the cutting profile. Some guidelines are also given about the gauge-pad length and gauge-cutter characteristics to achieve improved steerability.

This simple method based on geometrical criteria allows quick estimation of not only the PDC bit steerability but also the maximum dogleg potential achievable by the bit when it is coupled with the steering system.

Introduction

It is well recognized today that the directional behavior of a drilling system is a complex coupling of bit directional responsiveness and mechanical behavior of the directional system, but a possible rock-formation effect¹ (anisotropy) must also be considered. This paper focuses on the directional behavior of PDC bits characterized by their walk tendency and steerability.

A previous paper² noted that the bit steerability and walk tendency were mainly a function of the bit profile and gauge-cutter and -pad characteristics. In this paper, we propose a simple methodology to classify PDC bits defined by their IADC bit profile codes (shown in Fig. 1). This methodology is based on a recent study of the directional behavior of PDC bits on the basis of theoretical models, numerical simulation, and pilot and field trials.²

Background

Definition. The directional behavior of a PDC bit is generally characterized by its walk tendency and steerability. To quantify the

walk tendency, Ho³ introduced the walk angle, which is the angle measured in a plane perpendicular to the bit axis, between the direction of the side force applied to the bit and that of the lateral displacement of the bit.² The walk angle quantifies the intrinsic azimuthal behavior of the PDC bit.

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

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

The lateral drillability (D_{lat}) is defined as the lateral displacement per bit revolution vs. the side force. The axial drillability (D_{ax}) is the axial penetration per bit revolution vs. the weight on bit (WOB). The B_S (equivalent to the bit anisotropic index^{3,4}) 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. High steerability for a bit implies a strong propensity for lateral deviation, enabling maximum dogleg potential.

Bit Design. The PDC bit should have some stabilization and durability requirements as well as the ability to respond properly and rapidly to a side force applied by the steering system to initiate a deviation. To do so, the bit must have a steerability compatible with the directional system. The design of the bit should consider the three parts (see Fig. 2) that interact with the rock formation—the cutting structure (mainly the cutting profile and back-rake angle), the active gauge (gauge cutters or trimmers), and the passive gauge (conventionally called the gauge pad).

Cutting Profile. A recent study² has shown that the steerability of a PDC cutting structure depends greatly on the bit profile; the flatter the profile, the more steerable the bit is. The authors also found that the walk angle of a PDC cutting structure can be approximated by a simple equation linking the inner cone depth, C ; the outer structure height, G ; and the PDC back-rake angle (ω_c).²

$$\alpha_{CS} = \arctan \frac{2(C - G)}{\tan(\omega_c + \theta_j)(C + G)} \dots \dots \dots (2)$$

Eq. 2 is appropriate only for bits with identical back-rake angles along the bit profile and indicates that the walk tendency (right, neutral, and left) of the cutting structure is defined through the inner cone depth, C , and the outer structure height, G .

- $G > C$: left walking tendency.
- $G \approx C$: neutral walking tendency.
- $G < C$: right walking tendency.

Note that it is easy to extend Eq. 2 to take into account a gradual increase of the back rake from the inner cone to the gauge.

O’Hare and Aigbekaen⁵ conducted a study to evaluate the directional responsiveness of various bit profiles that were classified according to IADC codes. The authors give some guidelines on IADC bit profile codes to measure the bit’s tendency to achieve particular build and walk rates. For example, deep-coned PDC bits (IADC bit profile types 1, 4, and 7) tend to be directionally stable, and single-cone bits (IADC bit profile types 6 and 9) tend to be directionally isotropic (responsive in any direction). Even though these general rules are helpful for selecting PDC bits, it is known that the directional behavior of a PDC bit is not the only parameter in the well-deviation process.² Moreover, bit steerability depends

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