PDC bit technology improvements increase efficiency, bit life

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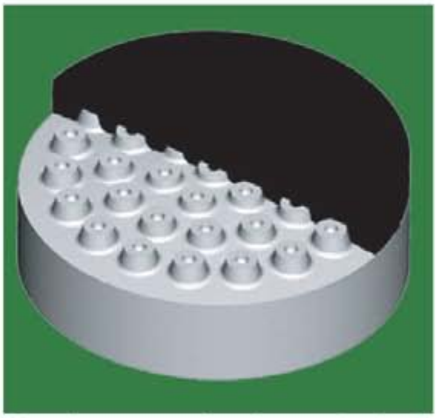
PDC (POLYCRYSTALLINE Diamond Compact) bits were introduced in the oil and gas industry in the mid 1970s. During the past 30 years, numerous technological improvements brought to the PDC cutters and bits have enabled them to take an important and growing share of the drilling bit market (50% of the total footage drilled in 2003 was with PDC bits compared to 26% in 2000). The total revenue of PDC bits sales in 2003 was around $600 million.

Improvements in PDC bit hydraulics, PDC cutter (tougher and more abrasion resistant cutter) and PDC bit dynamic stability have resulted in continuously and significantly increasing the average rate of penetration (ROP) and bit life of PDC bits, and extend their application in harder and more abrasive formations.



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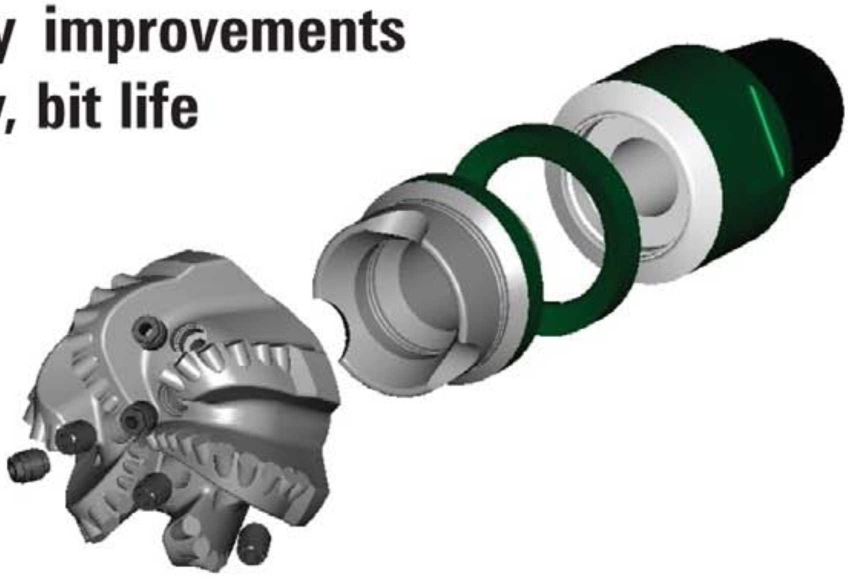

The different components of matrix PDC bit. As opposed to roller cone bits, PDC bits have no moving parts. PDC bits can be manufactured from two different materials, steel bodied and matrix bodied bits.

Historically, the use of PDC bits has been restricted to soft to medium and non-abrasive formations.

Today, thanks to the numerous innovations and technological breakthroughs, PDC bits drill faster, better and deeper, extending their application in harder and more abrasive formations, but basics remain.

MATERIAL

PDC bits, as opposed to roller cone, have no moving parts. The body of PDC bits can be manufactured from two different materials, steel bodied and matrix bodied bits. The steel bodied bit, machined and manufactured with steel stock, is better able to withstand impact load than matrix bodied bits. Steel bodied bits are generally preferred for soft and non-abrasive formations and large hole size.

The main disadvantage of steel is that it is less erosion resistant than matrix and, consequently, more susceptible to wear by abrasive fluids.

To reduce the bit body erosion, bits are "hardfaced" with a coating material that is more erosion resistant, and sometimes receives an anti-balling treatment for very sticky rock formations such as shales.

Matrix bits are manufactured with tungsten carbide, which is more erosion resistant than steel. They are preferred in high solid-content drilling mud.

The PDC cutters are composed of a thin (up to 3.5 mm) layer of polycrystalline diamond bonded to a cemented tungsten carbide substrate. These PDC cutters are generally cylindrical (diameter generally from 8 mm up to 24 mm) but may become available in other forms (oval or triangle) and are generally chamfered to increase the cutter's impact resistance.

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The interface geometry between the diamond layer and the tungsten carbide substrate are also improved. Due to the thermal limitations of the PDC (above 700°C the diamond layer disintegrates as a consequence of cobalt expanding), much work has been done to produce a Thermally Stable Polycrystalline (TSP) cutter, stable up to 1,150°C.

Cutters are attached to the bit body using an alloy that must have the lowest possible melting point, good flow properties, excellent wettability and shear strength, and bond well to tungsten carbide at low temperatures. The brazing is a critical operation in PDC bit manufacturing. Silver is the predominant element in these alloys.

Its highly controlled chemistry is necessary to provide the strength needed to braze the cutting elements to the matrix bit body to be able to translate weight and rotation to the cutting structure.

CUTTING MECHANISM

PDC bits drill the rock formation by shearing, like the cutting action of a lathe, as opposed to roller cone bits that drill by indenting and crushing the rock. The PDC bit's cutting action plays a major role in the amount of energy needed to drill a rock formation, and can be modelled by studying the interaction between a single PDC cutter and the rock formation. Many models have been developed during the last 30 years to predict forces on the PDC bit.

The single cutter-rock models generally take into account the PDC cutter characteristics (cutter size, back rake angle, side rake, chamfer, etc.) and the rock mechanical properties to calculate the forces necessary to cut an amount of rock.

The 2D or 3D rock-bit interaction model takes into account the bit characteristics (profile, cutter layout, gauges) and the bit motion to calculate the weight on bit (WOB), torque on bit (TOB) and side force on the bit at given operating conditions in a given rock formation (isotropic and heterogeneous formations).

Laboratory single-cutter tests and full-scale PDC bit tests carried out at atmospheric pressure or under borehole conditions tend to validate these models, enabling many advances made in bit design and optimization.

BASICS DESIGN FEATURES

The design of a PDC bit is largely a compromise between many factors, such as drillability (ROP), hydraulics, steerability or durability. Before we develop the particularity of these factors, let's go back to the basic design features of a PDC bit.

The design considers the three parts that interact with the rock formation: the cutting structure (bit profile and cutter layout characteristics), the active gauge (gauge cutters or trimmers), and the passive gauge (gauge pads).

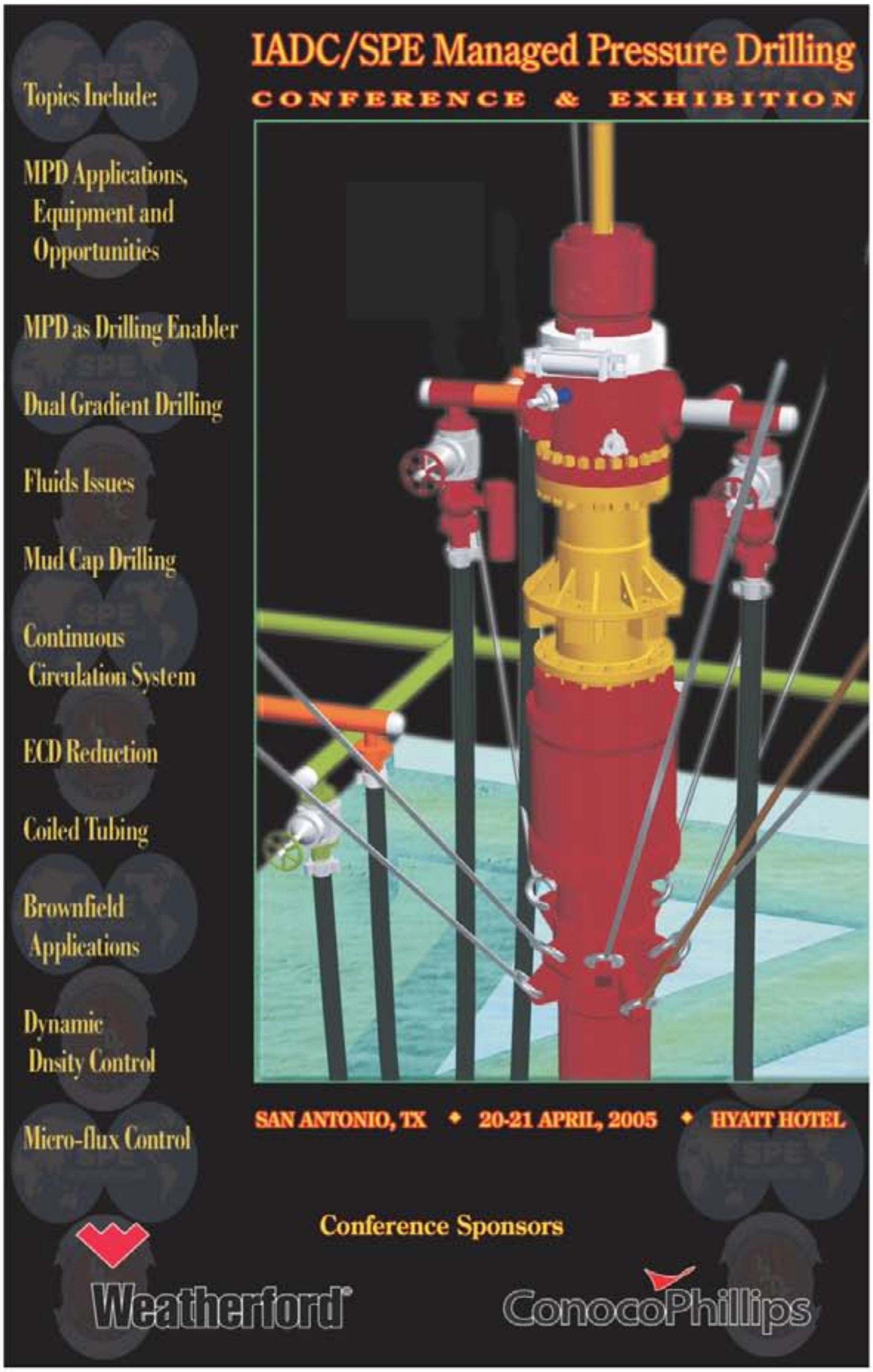
There are three basic types of PDC bit profile: flat or shallow cone, tapered or double cone and parabolic, according to the IADC fixed cutter drill bit classification (nine bit profile codes). The type of profile plays an important role for the bit stability and drillability, and bit directional responsiveness.

The choice of bit profile depends upon the type of application, and it is difficult to give some general rules. Nevertheless, let's say that the bit cone tends to make the bit more stable, and that very flat profiles are generally used for sidetrack applications.

The active gauge formed by the PDC's truncated-at-bit diameter constitutes the transition zone between the cutting structure and the passive gauge. These trimmers can be pre-flatted or rounded.

The passive gauge (or gauge pad) plays an important role in the stability and in the directional responsiveness of the PDC bit.

The passive gauge is reinforced by tungsten carbide inserts, diamonds or TSP to maintain the full gauge diameter of the drilled hole.



DRILLABILITY

PDC bit drillability is certainly the most important factor affecting global drilling costs. The PDC cutter characteristics, back rake angle, cutter layout, cutter count and cutter size are the main parameters that control the drillability of the bit.

The back rake angle is defined as the angle the cutter face makes with respect to the rock. The back rake controls how aggressively cutters engage the rock formation.

Generally, as the back rake is decreased, the cutting efficiency increases (high ROP) but the cutter becomes more vulnerable to impact breakage. A large back rake angle will result in lower ROP but will enable to give a longer PDC bit life.

The side rake generally affects the cleaning of the cutters, as it helps to direct the cutting toward the periphery of the bit.

PDC cutter count and size are selected for a specific formation under specific operating conditions.

The general rule is that small cutters and high cutter count are chosen for hard and abrasive rock formation, whereas large cutters and a reduced cutter count are preferred for soft to medium formation. The cutter count determines the number of blades required.

STABILITY

PDC bit stability is extremely important for the global drilling performance. A stable bit increases rate of penetration and bit life, improves hole quality and reduces the damage caused to downhole equipment.

The three main vibration modes are axial, resulting in bit bouncing; torsional, resulting in stick-slip; and lateral, resulting in whirl motions.

Considerable research in PDC bit dynamic led to highly balanced PDC bits (minimization of imbalance force), in particular as a result of the developments of spiralled blades.

Other techniques are anti-whirl bits, low-friction gauge pad, and full gauge contact design to make the bits more stable.

A widely spread innovation consists in placing some impact arrestors (small round inserts) behind the PDC cutters, which provide a better stabilization to axial and lateral modes of vibration.

STEERABILITY

The steerability of a bit corresponds to the ability of the bit to initiate a deviation. For example, high steerability for a bit implies a strong propensity for deviation, enabling a maximum dogleg potential.

Generally speaking, and all things being equal, the short-gauge design is more steerable than long-gauge design, but may lead to poor borehole quality.

To enhance toolface control during the sliding phase of a mud motor, some PDC bits have been designed to control lateral and axial aggressivity. This enables the directional driller to control a PDC bit as well as a roller cone bit.

DURABILITY

Advancements in PDC cutter technology have increased the development and performance of PDC bits. Cutters have mainly been evaluated in terms of their resistances to impact and abrasion because the primary reasons of bit failure are abrasive damage and impact loading damage.

Additionally, other characteristics such as interface strength, thermal stability and fatigue are also analyzed. Maximizing these properties improves cutter durability that subsequently enhances PDC bit performance and drilling efficiency.

HYDRAULIC

The size of nozzles (made of tungsten carbide) that are interchangeable depends on many factors, the main factors being the size of the bit and the recommended hydraulic program. The bit hydraulic is fundamental for two main purposes.

First, the drilling mud cleans the cuttings from the bit and prevents bit balling. Secondly, the mud cools the cutters to maintain the temperature below the critical 700°c.

The conventional nozzles are circular and create a symmetric pressure distribution at the rock interface.

Some improvements have been the development of nozzles with non-circular jets (fluted jets) with specialized interior shapes.

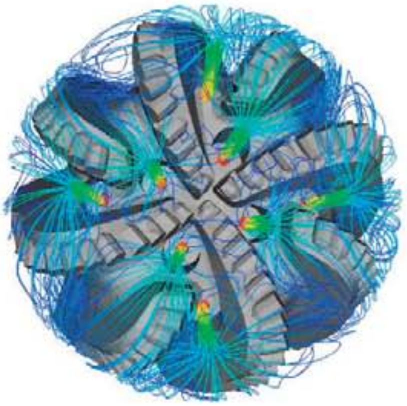
This enables a more efficient cleaning and cutter removal (increased turbulence under the bit) resulting in a higher ROP. Computational fluid dynamics (CFD) programs enable modelling the fluid flow around bits inside a borehole, to investigate quickly many bit designs and optimize fluid flow.

PDC BIT SELECTION

Today, a PDC bit is designed for a specific application, depending mainly upon the rock formation to be drilled. It is therefore important to study the type of rock encountered during drilling, using data and logs from offset wells.

The mechanical and physical characteristics of the formation (compressive strength, abrasiveness, elasticity, stickiness, pore pressure) govern the choice of PDC bit.

Advanced design software can estimate rock strength from well logs and evaluate PDC bit performance to help in drilling bit selection. At the same time, drilling parameters or hydraulic aspects should also be studied to adjust the bit design.



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PDC bits are also chosen for the type of application: directional drilling, slim hole, horizontal, motor drilling, turbodrilling, reaming drilling (bi-center bits) etc.

Today, most bit manufacturers have their own line of PDC bits for rotary steerable systems (RSS), their own specialized PDC bits for drilling salt or shales, or for any particular application.

The objective is always the same: to drill as fast as possible in a smooth way, and terminate the run with minimum wear to reduce overall drilling costs. ■