

A New Approach to Fixed Cutter Bits

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1. Ortiz B, Casallas C and Parra H: "Improved Bit Stability Reduces Downhole Harmonics (Vibrations)," paper IADC/SPE 36413, presented at the IADC/SPE Asia Pacific Drilling Technology Conference and Exhibition, Kuala Lumpur, September 9–11, 1996.
2. Bit whirl occurs when a bit's axis of rotation is not in line with the bit's physical center. Instead, one of the cutters becomes an instantaneous center of rotation, forcing the bit to rotate about this contact point rather than about the bit center. As the bit rotates about this contact point, friction builds between the wellbore wall and bit, and torque in the drillstring increases, which can force the bit to move in reverse relative to the surface rotation of the drillstring, or laterally, creating high-impact loads on the bit and BHA.

For more on bit whirl: Centala P, Challa V, Durairajan B, Meehan R, Paez L, Partin U, Segal S, Wu S, Garrett I, Teggart B and Tetley N: "Bit Design—Top to Bottom," *Oilfield Review* 23, no. 2 (Summer 2011): 4–17.

Brett JF, Warren TM and Behr SM: "Bit Whirl: A New Theory of PDC Bit Failure," paper SPE 19571, presented at the 64th SPE Annual Technical Conference and Exhibition, San Antonio, Texas, USA, October 8–11, 1989.

3. Allamon JP, McKown T, Hill D, Brooks BA, Bayoud BB and Winters WJ: "Diamond Bit Handling and Operation," paper SPE/IADC 16144, presented at the SPE/IADC Drilling Conference, New Orleans, March 15–18, 1987.

The goal of drillers everywhere is to drill as quickly as possible from casing shoe to casing point without compromising borehole quality. The bit, which must withstand variations in lithology, formation compressive strength and numerous other factors, is central to achieving this goal. A new bit, which has conical diamond cutting elements arrayed across its face, is attaining extended run lengths and increased penetration rates through challenging formations. This bit also delivers higher build rates and a balanced steering response in directional drilling applications.



The price of drilling into certain formations is paid in terms of shock and vibration to downhole tools, slow penetration rates and damaged bits. Hard or abrasive sandstones, interbedded sands and shales, conglomerates, carbonates containing chert and clays containing pyrite are particularly tough on drill bits. Encounters with such formations may compel drillers to trip out of the hole to exchange their damaged bit for something harder.

Diamonds, one of the hardest materials in the world, have been used in drilling applications since about 1910, when they were first used in coring bits. By the early 1920s, they were incorporated into fullbore drill bits. In the 1970s, synthetic diamonds, bonded onto tungsten carbide, led to the development of fixed cutter polycrystalline diamond compact (PDC) bits. Further advances in materials science and manufacturing have led to a new generation of fixed cutter PDC bits, which continue to evolve to meet the challenge of drilling in variable lithologies and along complex trajectories. However, even a PDC cutter is subject to chipping and impact damage that can slow progress or force the driller to trip for a new bit.

Although rate of penetration (ROP) typically increases following a bit change, the time spent tripping out of the hole and back to bottom is flat, or nonproductive, time not spent on drilling, which adversely impacts efficiency and drilling costs. The most obvious way to increase drilling efficiency and reduce costs is to drill from the casing shoe to the next casing point as quickly as possible using just one bit. When this ideal is not attained, operators must choose between staying on bottom and enduring lower penetration rates or tripping for a new bit to increase ROP. Each choice exacts a penalty in terms of rig time. Often, bit selection requires a compromise that balances impact and wear resistance against ROP.

Within local basins, bit selection is typically driven by operator experience in drilling through a particular formation. Carbonate formations can be characterized by a range of lithologies—some of which are easier to drill than others—from soft marls and limestones to hard and brittle dolomites. Evaporites also present a variety of challenges, including cutter overload in hard anhydrites, inhibited drilling efficiency in laminated gypsum, and washouts in soluble salts. Clastics may reduce ROP when the cuttings stick to the bit and obstruct the bit's junk slots and waterways. Sandstones and siltstones often cause abrasive wear. Some plays lie beneath basalts, which can be especially hard and abrasive.

Formation depth also plays a role in bit selection because formation compressive strength tends to increase with depth. Some formations are notori-

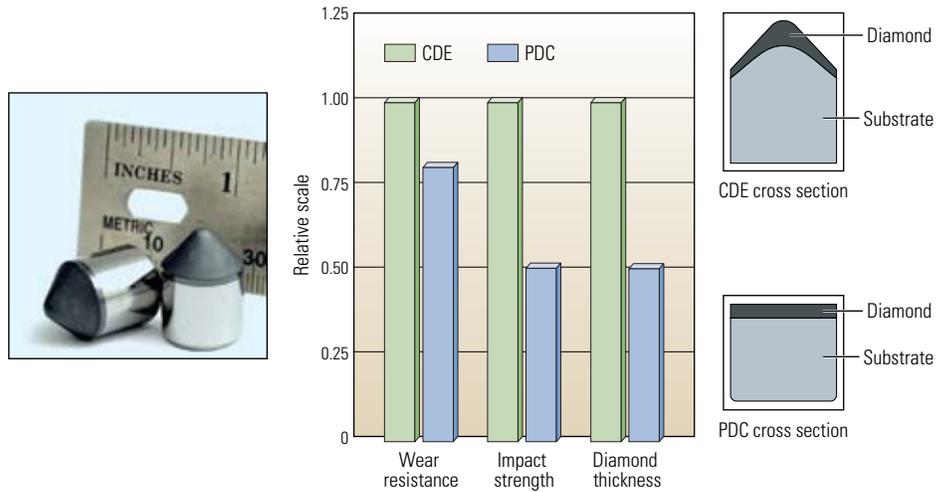


Figure 1. Conical diamond element (CDE). The Stinger CDE (*left*), manufactured under high temperature and pressure, has a layer of synthetic diamond that is substantially thicker than that of a conventional PDC cutter (*right*). The polycrystalline diamond material of the conical cutter is engineered to provide a level of impact strength and resistance to abrasive wear that is higher than that of the conventional PDC cutter (*center*).

ously hard, having compressive strengths that range from 207 to 380 MPa [30,000 to 55,000 psi] and, depending on thickness, may require several days and several bits to drill through.

Matching the right bit to a formation might not be so difficult but for the fact that most formations are not homogeneous. Frequently, multiple or mixed lithologies lie between the bit and the next casing point. And it is the abrupt transition from one rock type to another that can lead to bit damage and durability problems. Drilling from one lithology to another—or from one compressive strength regime to another—can produce high instantaneous impact forces, cyclic lateral forces and vibrations that can cause accelerated bit wear and failure. When retrieved to surface, a PDC bit that has failed because of vibration will have chips, fractures and gross cutter breakage—all attributable to severe impacts on the diamond table of the PDC cutting structure.¹

At the surface, lithologic changes may register as fluctuations in rotary torque or ROP, but such indicators only hint at what is happening downhole. A hard, abrasive sandstone, for example, may cause accelerated cutter wear or damage. Some otherwise soft shale formations offer deceptively hard drilling, owing to the presence of calcite concretions or pyrite nodules, which are significantly harder than the shale mass itself. Calcite [CaCO₃] concretions are formed through solution deposition and may range from a few cm to 30 cm [1 in. to 1 ft] in diameter. These concretions can have compressive strengths in excess of 260 MPa [38,000 psi], whereas the surrounding shale may have a compressive strength

of around 34 MPa [5,000 psi]. Similarly, small nodules of pyrite [FeS₂], often found in shale, can also be troublesome.

Drilling into a formation characterized by mixed lithologies can create intense cutter loading and cyclic lateral forces that cause bit whirl, which in turn, leads to impact damage of PDC cutters.² The formation characteristics, bit design and the required bit performance will determine if modification of operating parameters will support further drilling or warrant a trip for a new bit.³

In hard formations, the driller must increase weight on bit (WOB) to overcome the formation shear strength needed to fail the rock and maintain an acceptable ROP. However, higher WOB significantly increases cutter loading, which can lead to microchipping of the diamond table in PDC cutters. The bit dulls as the cutter wear flat area increases, which increases frictional heating at the interface between cutter and rock, potentially weakening the diamond cutting element.

Not only is transition drilling a problem; the capability to drill through a curve is a significant challenge for plays in which economics of production depend on lateral drilling. Building angle generates considerable torque at the bit and can create toolface control difficulties for some PDC bits, making it difficult to maintain trajectory.

To address these challenges, bit engineers developed a fixed cutter bit that employs a unique type of cutting element. The Stinger conical diamond element (CDE) provides a significantly thicker layer of diamond than do conventional PDC cutters (Figure 1).

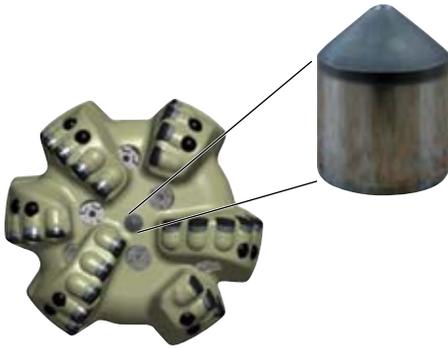


Figure 2. Centrally placed conical diamond element (CDE). By removing cutting structures from the bit center (*left*), space is created for the CDE (*right*). During drilling, this space leaves a small column of rock, which is easily crushed by the CDE.

The StingBlade conical diamond element bit incorporates an array of Stinger cutting elements across the bit face. Depending on the application, these cutting elements may be positioned anywhere from bit center to gauge. This cutter array has enabled operators to improve ROP and drill significantly longer intervals than was possible using conventional PDC bits. In some wells, StingBlade bits were able to drill continuously from shoe to casing point in a single run through formations in which this was previously impossible. In addition, the new bit design has provided improved toolface control in challenging directional applications. The following discussion

focuses on the StingBlade bit, its design and its performance in drilling some of the toughest formations around the world.

Bit Design

The Stinger conical diamond element was initially introduced as a stand-alone cutting element placed at the bit center to improve ROP and enhance dynamic stability for PDC bits (Figure 2). In this center position, the conical element fractured and crushed the rock as the PDC cutters sheared the rock.⁴ The design team at Smith Bits recognized the potential for increased drilling efficiency using multiple Stinger elements to fail the rock through a combination of shearing and plowing actions. Bit design engineers used finite element analysis (FEA) to experiment with CDE cutter placement and to model the resulting changes in drilling performance.

The conical elements were placed at various positions across the bit face. This design process yielded a stronger overall cutting structure compared with that of conventional fixed cutter PDC bits. As they experimented with Stinger element placement across the bit face, the design engineers recognized the potential for improving design configurations and the benefits of using specific configurations to address specific drilling challenges (Figure 3).

Testing the Hypothesis

Design engineers conducted a series of laboratory tests to evaluate Stinger conical diamond element

performance and durability. One test compared impact strength relative to that of a conventional polycrystalline diamond cutter element. Both elements were dropped onto a hardened steel block with an impact force of 80,000 N [18,000 lbf]. This experiment simulated typical transitional drilling conditions when a PDC bit drilling at an ROP of 18 m/h [60 ft/h] exits soft shale and penetrates hard limestone. On first impact with the steel block, the sharp edge of the conventional PDC cutter was severely damaged (Figure 4). By contrast, the conical element survived more than 100 impacts at 80,000 N without damage. Greater impact resistance of the CDE, which has a thicker diamond layer, translates into extended run lengths and improved penetration rates in impact-prone settings.

In a separate test, a vertical turret lathe was used to measure wear resistance. The conical element was lowered onto a rotating test bed of granite having a compressive strength of 207 MPa [30,000 psi]. After force was applied to the CDE, depth of cut and amount of wear were measured. Compared with a standard PDC cutter, the conical element exhibited greater wear resistance and cutting efficiency. For example, under an applied force of 5,300 N [1,200 lbf], a 0.5-mm [0.02-in.] depth of cut by the CDE resulted in a 70% increase in cutting efficiency; at 1.3-mm [0.05-in.] depth of cut, the CDE cutter was 35% more efficient.⁵ The results also showed that the conical element dissipated frictional heat more efficiently than did conventional PDC cutters.

To investigate the conical element's capability to induce rock failure, bit design engineers turned to FEA modeling, which allowed them to evaluate the Stinger element's performance within the controlled environment of a virtual downhole setting. The FEA modeling demonstrated that the conical diamond element exerts concentrated point loading to fail high-compressive strength formations. By creating a high-stress concentration at the contact point, the CDE increases fracture generation at the rock face while requiring significantly less applied force compared to that of standard PDC cutters.⁶

Through FEA modeling, engineers investigated the effects of conical elements on bit and BHA stability by comparing the forces sustained by conventional PDC cutters with those of CDE cutters. Among the most destructive products of those forces are lateral and axial vibration. In addition to damaging downhole equipment, these vibrations create undesirable drillstring harmonics and divert mechanical energy from the drilling system, resulting in lower ROPs. The modeling

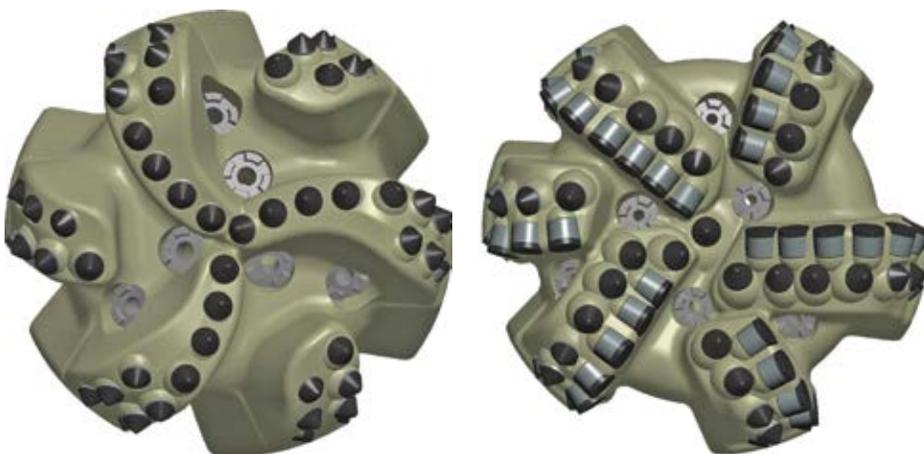


Figure 3. Variations in cutter placement. Depending on the application, cutter placement on the StingBlade bit may vary from single and double rows of CDE cutters (*left*) to alternating rows of PDC and CDE cutters (*right*).



Figure 4. Impact testing. A technician prepares cutters for testing (*left*). Still images from a motion picture indicate that the conventional PDC cutter (*center*, gray rounded element) failed on the first impact; the conical diamond element survived 100 impacts without damage (*right*).

showed that the balanced profile of the conical diamond element subjects the cutter to less lateral force, which provides greater stability for longer bit runs while mitigating shock and vibration effects to prolong the life of LWD and steering components in the BHA (Figure 5).

The design process also led bit engineers to surmise that the plowing action of the conical ele-

4. Bruton G, Crockett R, Taylor M, DenBoer D, Lund J, Fleming C, Ford R, Garcia G and White A: "PDC Bit Technology for the 21st Century," *Oilfield Review* 26, no. 2 (Summer 2014): 48–57.
5. Azar M, White A, Velvaluri S, Beheiry K and Johnny MM: "Middle East Hard/Abrasive Formation Challenge: Reducing PDC Cutter Volume at Bit Center Increases ROP/Drilling Efficiency," paper SPE/IADC 166755, presented at the SPE/IADC Middle East Drilling Technology Conference and Exhibition, Dubai, October 7–9, 2013.
6. German V, Pak M and Azar M: "Conical Diamond Element Bit Sets New Performance Benchmarks Drilling Extremely Hard Carbonate/Chert Formations, Perm Region Russia," paper SPE/IADC 173144, presented at the SPE/IADC Drilling Conference and Exhibition, London, March 17–19, 2015.

ment might produce less torque than the shearing action of conventional PDC cutters. To confirm this hypothesis, the engineers subjected the bit to extensive testing, starting with FEA modeling, followed by evaluations in their rock mechanics laboratory. Next, downhole testing was carried out at a wellsite on the grounds of the Schlumberger Cameron Test and Training Facility in Texas, USA. This test compared the directional response of a StingBlade bit to that of a conventional PDC bit as each drilled a curve section through interbedded limestone, shale and sandstone that had compressive strengths ranging from 69 to 103 MPa [10,000 to 15,000 psi]. The bit tests were conducted from identical kickoff points in adjacent wells on the same pad, using the same rig, motor type and directional driller. The StingBlade bit attained 23% higher build rates. It also exhibited better toolface control, requiring less intervention by the directional driller to stay

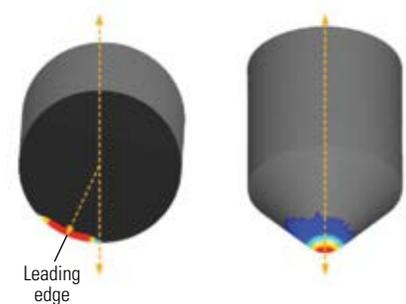


Figure 5. Stability as a function of resultant lateral force. The FEA modeling shows how resultant lateral force, applied by combining weight on bit with torque, is distributed at the cutter element. When applied to a conventional PDC cutter (*left*), the forces (dashed orange lines) are spread along the leading edge of the cutter. The forces concentrate more symmetrically at the tip of the conical element (*right*). Balancing this distribution of resultant lateral forces is key to reducing lateral shocks and vibrations induced at the drill bit.

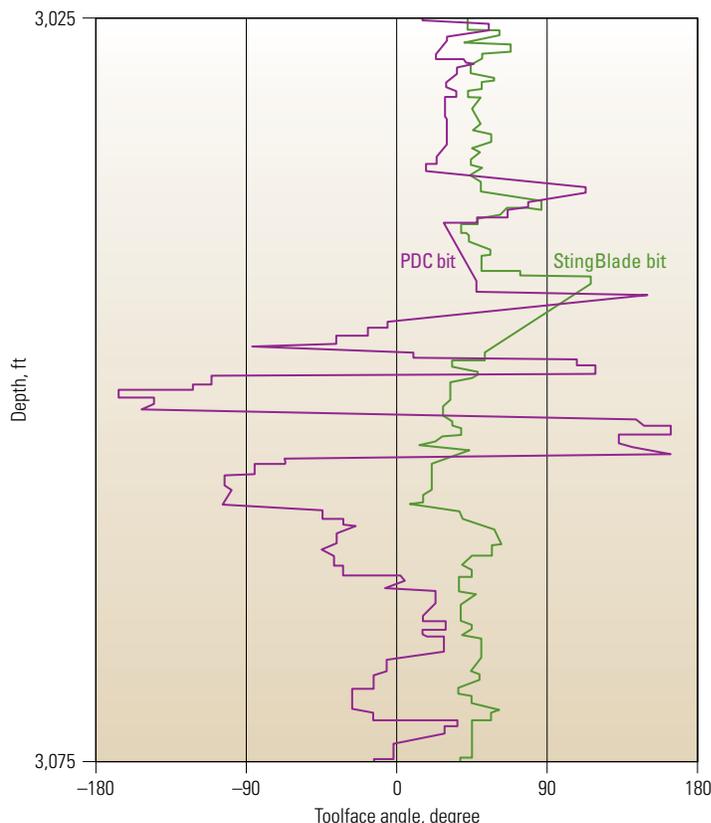


Figure 6. Toolface angle. Changes in mud motor toolface orientation served as a gauge of downhole torque in field tests comparing PDC bit performance with that of a CDE bit. Despite changes in drilling parameters, such as weight on bit, the StingBlade bit experienced low fluctuations in reactive torque while building angle through formations of varying compressive strength.

on target (Figure 6). The higher build rates delivered by the StingBlade bit enabled it to land the curve 20 m [65 ft] sooner than the standard PDC bit.

Drilling the Curve in Variable Lithologies

In Lea County, New Mexico, USA, Cimarex Energy is targeting the Delaware basin Avalon shale

play.⁷ There, wells are typically drilled vertically to the Bone Spring Limestone, then kicked off with a bent sub and motor. The directional driller builds angle to 90° at 12°/100 ft [12°/30 m], to land the wellbore in the Avalon shale, after which the well is extended horizontally. The Avalon shale contains numerous stringers of interbed-

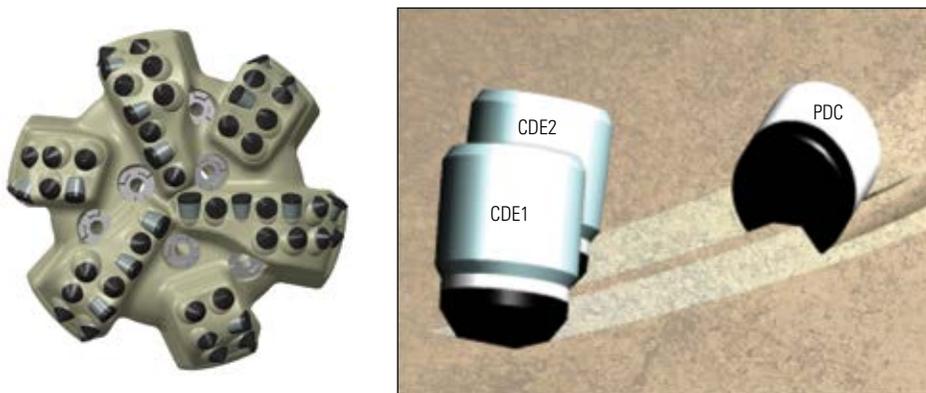


Figure 7. Alternating CDE and PDC cutting elements. Using FEA modeling of cutting action, bit engineers created a StingBlade bit design to plow, then shear the rock (left). Stinger cutting elements create troughs separated by a small ridge (right). This ridge of stress-relieved rock is then easily sheared by the PDC cutter.

ded carbonates and is characterized by unconfined compressive strengths ranging from 9,000 to 30,000 psi [62 to 207 MPa].

The highly variable lithology creates challenges for directional drillers in the form of bit whirl and axial, lateral and torsional vibrations. These problems cause the bent motor assembly to deviate from its intended course, thus forcing the directional driller to reorient the toolface and adjust the trajectory to get back on target. Each toolface adjustment creates additional time not spent drilling in the desired direction, resulting in a longer curve section and increased potential for missing the target.

In general, standard fixed cutter bits can be affected by variable formations, as evidenced by erratic toolface control and difficulty in drilling tight curves. Consequently, operators in this area typically rely on roller cone bits to drill the curve and have lately turned to a premium roller cone hybrid bit. These bits produce consistent torque responses for better steering control; however, they also drill at lower ROPs than do PDC bits.

Although the operator had success with the roller cone hybrid, the bit did not consistently drill the entire curve in a single run. A review of bit records for nine wells drilled by Cimarex within five miles of the target wellsite showed completion of the curved section using one bit in only 55% of the wells and an average ROP of 20.8 ft/h [6.34 m/h].

Based on bit performance and wear analysis in offset wells, Smith Bit engineers evaluated key areas along the bit face to determine where CDE placement would prove most effective. Using the IDEAS integrated drillbit design platform, they developed a fixed cutter bit having an alternating CDE and PDC cutter configuration. With this design, the conical diamond elements score the rock, creating two adjacent troughs. A PDC cutter, which trails behind the pair of CDEs, then shears away the unconfined rock ridge between the troughs (Figure 7). This arrangement requires lower force than is needed using traditional PDC cutting structures, providing more efficient rock removal with less reactive torque.

Cimarex engineers selected an 8½-in. StingBlade bit to drill the curve interval in its next two Avalon shale wells. Each bit drilled the curve in just one run with no significant toolface

7. Hempton R, Copeland C, Cox G, Faught J, Blackmon W, Prewitt E, McDonough S and White A: "Innovative Conical Diamond Element Bits Drill Back-to-Back Tight Curves in One Run, Improving Economics While Reducing Risk in Avalon Shale Play, New Mexico," paper SPE 175534, presented at the SPE Liquids-Rich Basins Conference—North America, Midland, Texas, September 2–3, 2015.

8. For more on the ONYX 360 rolling cutter: Bruton et al, reference 4.

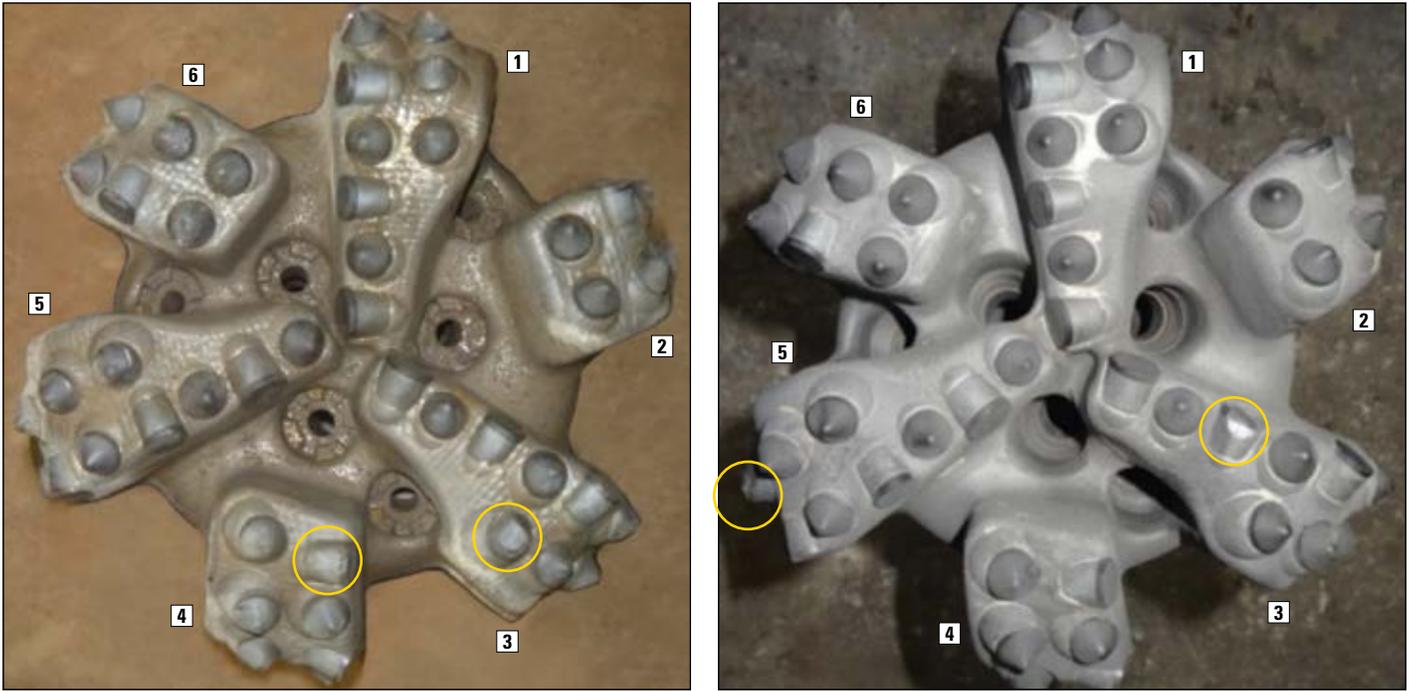


Figure 8. Conical diamond element bits after a full curve run. Bits pulled from wells are assessed using industry standard dull grading criteria. Increasingly, these assessments are supplemented with digital photographs. The first bit (*left*) displayed slight chipping on one Stinger element in the trailing position on the nose of Blade 3 and on one PDC cutter on the nose of Blade 4 (circled). The bit pulled from a second well (*right*) shows a delaminated and worn PDC cutter in the cone of Blade 3 and a chipped and worn CDE cutter on the shoulder of Blade 5 (circled).

control problems. The configuration of the conical diamond elements also helped protect the PDC cutters; when pulled from the hole, the bits were graded in very good condition (Figure 8). Furthermore, protection of the PDC cutters contributed to an improvement in ROP. Compared with bit performance from the previous nine wells, the StingBlade bits were able to complete the curve interval at an ROP that was 36% faster than the average roller cone hybrid one-run bit.

Broader Horizons

Advances in bit design software, materials science and manufacturing enable bit engineers to not only test their ideas in the laboratory but to also see their designs come to fruition within days of conception. As a result, the variety of StingBlade bit designs is expanding rapidly to address a number of challenges. Already, Stinger cutting elements are being mounted on steel or composite bit bodies of various blade configurations, fre-

quently in conjunction with conventional PDC cutters or with ONYX 360 rolling cutters.³

Variations on the original design now include several types of StingBlade bits in a range of bit diameters (Figure 9). Although early StingBlade bit designs addressed specialized applications, its versatility is allowing the Stinger conical diamond element to quickly expand into more routine applications. —MV

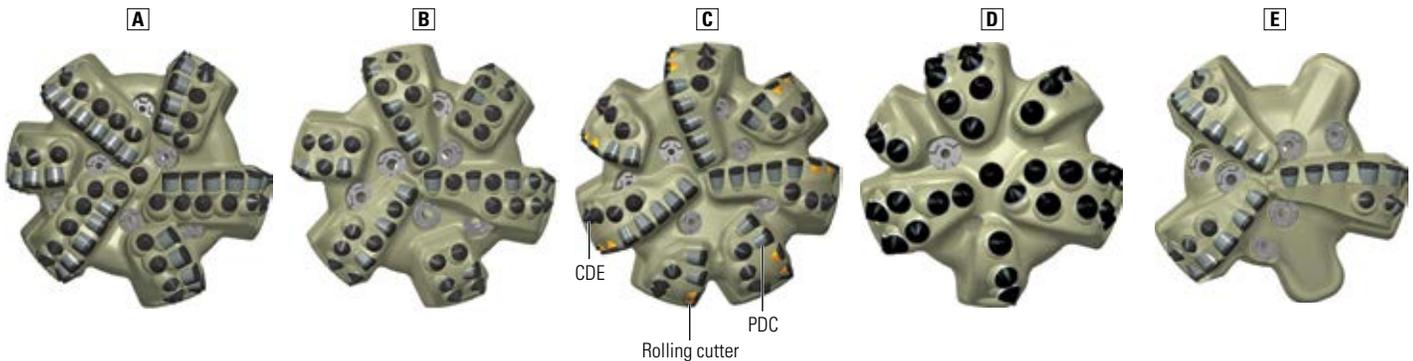


Figure 9. StingBlade bit variations. Of the dozens of configurations designed for different drilling applications, five examples are shown. Designed for drilling hard carbonates with high concentrations of chert, this bit (A) uses Stinger elements to help support PDC cutter loading in applications that have potential for impact damage. Designed for highly interbedded formations, this bit (B) has alternating PDC and Stinger elements on the leading position of each blade to reduce torque variation and improve toolface control for curve intervals. A third variation (C), for hard, abrasive formations, uses Stinger elements to help support PDC cutter loading; ONYX 360 rolling cutters are strategically placed for wear resistance. Another design utilizes Stinger elements only (D); this bit is intended for granites or other extremely hard, abrasive igneous rocks. The Stinger cutting elements provide high concentrated point loading to fail the rock. Utilized in soft formations with hard stringers, the three-bladed bit (E) tends to drill faster than conventional five-bladed bits; the Stinger elements protect the PDC cutters from impact damage while the bit is transitioning through hard stringers.