Q&A

DRILL BIT DESIGN

OILFIELD TECHNOLOGY INVITED EXPERTS FROM BHGE, ULTERRA, AND VAREL TO SHARE THEIR KNOWLEDGE ON A VARIETY OF DRILL BIT DESIGN TOPICS. READ ON FOR INSIGHTS FROM:

BHGE

AFTON NOEL is the Product Line Manager, responsible for BHGE's polycrystalline diamond compact drill bits product offering.

STEFANI REED is the Kymera Product Line Manager, responsible for BHGE's hybrid drill bits product offering.

ULTERRA

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VAREL

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CUTTER CONFIGURATION AND DESIGN

BHGE – AFTON NOEL

Drilling into abrasive and interbedded formations, in both conventional and unconventional plays, presents drillers with a myriad of challenges that hinder drilling efficiency and raise well costs. Traditional cutter geometries are unable to withstand the high loads in harsh drilling environments, which results in increased friction and heat generation at the cutter/rock interface. Cutter durability suffers, as does the rate of penetration (ROP) of the bit through the rock.

Baker Hughes, a GE company (BHGE), developed its Optimus ShockWave shaped cutter to address the challenges of durability in difficult formations. Featuring a design that extends cutter life, the new cutter affords faster and farther drilling in the same run. The cutter geometry increases stress on the rock, enabling the rock to fracture with less energy. As a result, the cutter drills like a single chamfer cutter but with the impact resistance of a dual chamfer cutter, which allows increased ROP at a given weight-on-bit (WOB).

The ShockWave's shape also moves the rock up the trough and breaks it into small cuttings that are projected away from the face of the cutters. This results in less heat buildup on the diamond table and a longer cutter operating life.

The cutter design and geometry have advanced drilling performance for a number of applications.

An operator in New Mexico was challenged with increasing their ROP and saving on drilling costs. BHGE developed the optimal shaped cutter geometry that improves cutter-rock interaction to boost drilling efficiency and increase durability through the formation. The shaped cutter worked as designed, breaking up the rock cuttings in the interbedded formation to improve efficiency and holding up better, with less wear, compared to offset runs. The new cutter improved ROP by 38% and reduced the operator's well costs by US$5.34/ft.

ULTERRA – CHRIS CASAD

The company's team of design engineers analyse individual cutter work load to reduce cutter imbalance and to ensure that the work is being distributed evenly amongst the cutters. Based on the drilling application, the cutter layout is adjusted to optimise drilling efficiency.

Critical to the success of the cutter layout is the quality of the cutters used. Ulterra's Omega™ cutter engineering team works with field sales, sales engineers, and design engineers to ensure the latest cutter technology is at work in the field. By maintaining a lean cutter inventory, customers are able to apply the latest cutter technology to their drilling operation. Operating at a fast pace that leaves little room for individual naming, Omega cutter technology is at the front of a constantly moving frontier of improvement.

To get the most from each cutter, every aspect of the target application is analysed to identify and address specific problems. Using proprietary tools built within Ulterra to seamlessly integrate cutter configurations with cutter and bit design technologies, specific operator challenges such as stick slip in shale formations are addressed with improved drilling mechanics.

These tools take into account a broad range of information from simulation results and manufacturing considerations, but most important is the evaluation of past and current real-world performance. Actual iteration in order to learn and continually evolve is still at the core of all successful bit designs. Results from field testing verify that the cutters, blades, and nozzles are all working together as a system to achieve the best performance.

VAREL - FEDERICO BELLIN

Pioneering research into shaped cutter design is providing a significant boost to ROP and footage drilled in the Permian Basin, Oklahoma Stack, Guatemala, and other wells around the world. The various cutter geometries allow cutting action to be matched to drilling conditions and objectives.

Cutter shapes with raised ridges, concave faces, and other non-standard geometries are the product of increasingly sophisticated integration of physical testing in the laboratory with computer modelling and simulation. Testing at Varel Oil & Gas Drill Bits' Houston Technology Center subjects cutter designs to realistic downhole temperature, impact, abrasion, and other tests before the bit is run in the hole.

The company holds 14 patents on PDC cutter testing and cutter design. This robust R&D capability is yielding significant insights and new avenues of research for improving drilling efficiencies. It is also speeding up the process between concept and field application to enhance the search for new options.

The company has developed a set of FORCE cutter geometries that fine-tune the bit's interaction with the rock. The OVAL, TRIFORCE, SCOOP, and FANG cutters each produce a different cutting action to reduce torque, pre-fracture the rock, create a progressive back rake, and enhance non-standard positioning on the bit.

Penetration rates drilling long, S-curve trajectories in Guatemala wells are being improved with OVAL cutters. In initial runs, bits equipped with the cutters more than doubled ROP in the medium hard formation. As the oval shape wears, it presents a smaller contact point, which produces more force with the same weight on bit. The cutters allowed a tighter cutter placement and more efficient cutting action with less reactive torque for better directional control.

In West Texas Delaware basin drilling, concave SCOOP cutters enhance ROP with a variable back rake. As the cutter shears deeper into the rock, the concave face presents a progressively higher effective back rake. The resulting increase in efficiency achieves greater ROP for an equivalent weight on bit.

The first regional run of a PDC bit equipped with the concave cutters drilled the lateral in the Bone Spring formation's shaley sand at 233.4 ft/hr compared to an offset average of 177.55 ft/hr. The prototype cutters also resulted in similar performance in the fine-grained sandstone, shale, and conglomerate of Oklahoma's Owego formation.

The ridged profile of TRIFORCE cutters concentrates force on the leading edge to fracture and plow through the rock. For the same amount of travel, the cutter removes a higher volume of rock to produce greater ROP.

In its initial use in the Delaware basin drilling dolomite, limestone shale, and sandstone, the first generation prototype cutter drilled 5932 ft at 73.7 ft/hr, compared to the average 77.6 ft/hr. achieved by the same bit fitted with conventional cutters. The initial success led to a second run in an Oklahoma STACK well. The shaped cutter bit drilled the interbedded sands, limestones, and shales at 70% faster ROP and 3.2% further than the offset average.

FANG cutters are scribe type cutters that are uniquely positioned on the cutting structure. The interruptive placement locates the scribe cutters in a secondary position to fracture and sweep rock. Pre-fracturing a smaller contact area allows a higher volume of rock to be removed per rotation of the bit. In an Oklahoma STACK well, the result was a 32.3% gain in average footage and a 52.8% higher ROP.

DIRECTIONAL DRILLING CHALLENGES

BHGE - AFTON NOEL

Slides on conventional motor assemblies often account for up to 50% of drilling time, and yet only 10 - 15% of the distance drilled.

BHGE developed its Dynamus AntiWalk drill bit technology to deliver improved directional control with minimal sliding. Historically, the industry has tried to mitigate bit walk by limiting operating parameters or making changes to the bottomhole assembly (BHA) design. The current mitigation method calls for extending the length of the bit's gauge to minimise lateral deviations. These solutions often do not go far enough to mitigate bit walk in wells with unplanned deviations or long laterals.

The drill bit design includes an engineered gauge pad with a stripe that manages side cutting response using lateral depth-of-cut (DOC) control. This improves tracking to hold azimuth and inclination, which increases rate of penetration (ROP) and reduces dogleg severity for improved wellbore quality and a more efficient completion design.

The new gauge pad design has the operational flexibility to achieve the planned build-up rate in the curve section while remaining on target through long laterals. The bit's design provides the benefits of tracking without the challenges of sliding with a longer gauge bit, thus improving the overall AFE.

In the Delaware basin, a 6 ¾ in. AntiWalk drill bit reduced the variation in dogleg severity compared to the standard drill bit offset. This translated to a 48% reduction in the time spent sliding, a 33% improvement in ROP, and a saving of nearly two days in drilling time.

ULTERRA - CHRIS CASAD

One of the most significant trends in directional drilling is the effort to combine directional and lateral sections, using the same drill bit, in order to reduce time, save trips, and cut costs. In addition, rotary steerable system (RSS) usage is on an upward trend throughout most basins with more than 1100 RSS runs this year in the Permian Basin alone.

With the increase in RSS usage, as tool pricing has improved, operators are looking to go farther into the lateral sections of their wellbores, in order to make the most of future completions. Improved bit stability, durability, and steerability are critical factors in addressing these objectives, allowing the bit to drill effectively in all sections of the well, and to hit the extended depth targets. In lateral sections, improved control and stability allows operators to end up with a cleaner bore hole, resulting in higher-outputting completions.

Ulterra's SplitBlade™ PDC bit technology has seen success in combining directional and lateral sections, achieving record ROP and total footage on both RSS and traditional motors. This performance has been realised in the Permian basin on an AutoTrak RSS, drilling a record curve and lateral performance that increased ROP by 23% over the competition at 140 ft/hr. Also, recently, in a Woodford lateral in Oklahoma, an 8.5 in. SPL616 set a lateral RSS ROP record, drilling 178 ft/hr.

One of the unique challenges of directional drilling with various BHAs involves what happens to the primary cutters and gauge layout when drilling in the bend. Because the bit is drilling on a bias moving forward, lateral vibrations can be amplified. Considered one of the leading causes of RSS tool failure, the combination of SplitBlade and CounterForce® technology has proven a notable increase in bit life, resulting in more consistent section completions without a tradeoff in speed or directional control. Ulterra currently has the leading average dull grades from RSS runs in the Permian, Delaware, Eagle Ford, Anadarko, Marcellus, and Niobrara basins, supporting customers and operators to further push the boundaries of what is possible.

ROLLER CONE BITS

VAREL – JONATHAN HOWARD

Air drilling in the Utica shale play makes durability key to tungsten carbide insert (TCI) roller cone bit performance. Multiple bit runs are often required to drill a wellbore section, adding time, cost, and risk. The challenge is complicated by a diverse set of drilling parameters and wellbore profiles, including 27˚ tangents, drastic side loading, and increased motor torque ratios. In response, operators typically vary their configuration of bottom hole assemblies, which further subjects the bit to different wear forces.

In these circumstances, durability depends on withstanding multiple wear variables. It also depends on balancing ROP requirements to maintain an effective cutting structure through multiple transition zones and high compressive strength formations.

Varel Oil & Gas Drill Bits conducted an extensive study of bit wear in the Utica area and performed drilling simulations to explore design options. The A-FORCE bit featuring the resulting technology enhancements has drilled single run intervals to TD in almost a hundred Utica wells, and has improved penetration rates from 65 ft/hr to an average of 100 ft/hr.

The initial 12 ¼ in. application was in an Ohio drilling programme that historically required two bits to drill the section. The upper interval consists mostly of interbedded sandstones and limestones with UCS of 20 000 to 30 000 psi; under 5000 ft, a dolomite interval has UCS of 45 000 to 50 000 psi.

The operator wanted to eliminate a run. At the same time, penetration rates were generally good and they wanted to retain as much ROP as possible. At the time, the current Varel bit was making approximately 72 ft/hr compared to alternative bits, which were drilling at roughly 60 ft/hr.

Varel researched bit performance in the area and examined dozens of dull records and run reports. The study clearly identified gauge row wear in the form of rounding and insert damage. Various design options were considered to improve wear while optimising ROP. Computer simulations using Varel's proprietary AMP virtual drilling program were conducted to examine how the designs interacted with the rock under various drilling parameters.

The resulting enhancement to the A-FORCE bit design achieved the operator's first single run to TD, drilling more than 8200 ft and averaging 80 ft/hr with an on-bottom drilling time of 104 hrs. In offset wells, the average footage was 5026 ft at 78 ft/hr. All subsequent runs of the new design have reached TD in a single run with similar ROP performance.

Wear is greatly reduced and gauge is retained in these applications. A typical dull grade of 2-3-E-E-E contrasts with competitor dull grades of 8-8-F-F-F that are severely under gauge, especially in deeper Utica runs of more than 7000 ft. Staying in gauge at TD eliminates a reamer run to ensure casing is properly landed. Increased seal life and bearing life also contribute to longer bit life.

Within a month, the new bit design was used by a second Utica operator to drill a full, 4754 ft interval at 117 ft/hr ROP compared to an offset average of 3422 ft drilled at 72 ft/hr. Since then, the enhanced A-FORCE bit has consistently exhibited similar durability and ROP performance gains across a diverse set of Utica drilling parameters, wellbore profiles, and BHA.

STABILITY AND VIBRATION RESISTANCE

BHGE – AFTON NOEL

Mitigating vibrations during drilling is an ongoing challenge for most traditional polycrystalline-diamond-compact (PDC) bits, particularly as drillers continue to drill ever-longer sections in a single bit run. Lateral vibrations caused by torsional stick/slip and impact loading in interbedded formations can damage the bit and other parts of the BHA to lower rate of penetration and drive up drilling costs.

BHGE addressed the challenges that lead to lateral vibration with the development of the TerrAdapt adaptive drill bit, a self-adjusting PDC bit technology that dynamically adapts its depth-of-cut (DOC) to changing lithology. This ability to change DOC, with no interaction or direction from surface, quickly mitigates the onset of stick-slip, absorbs shocks, and helps prevent damage to the bit and BHA.

The bit achieves auto-adjustment through a passive hydro-mechanical feedback mechanism encapsulated in self-contained cartridges that are installed among the fixed blades. When vibrations are detected, the cartridges autonomously extend to mitigate sudden changes to DOC, thus preventing the bit from taking too large a bite into the formation and getting stuck. Once the vibrations subside, the cartridges slowly retract to enable the maximum ROP for that section of the well.

In the field, the TerrAdapt bit has proven its ability to optimise bit response and prolong cutting structure life, thus delivering real time performance, increasing efficiency, and reducing non-productive time.

In the Permian basin, an 8 ½ in. TerrAdapt drill bit, paired with BHGE's AutoTrak rotary steerable system (RSS), drilled the entire curve section of a well in 13.5 hrs, with an average ROP of 76 ft/hr. This was a 53% reduction in time spent to complete the interval compared to the average field offset. The solution gave the operator greater flexibility in their BHA design while helping them improve borehole quality.

SHALE AND 'UNCONVENTIONAL' OPERATIONS

ULTERRA – CHRIS CASAD

The majority of today's drilling operations involve unconventional applications, characterised by long laterals and deviated wellbores. In a formation such as the Eagle Ford, where Ulterra has experience drilling in shale, drilling may be fast, but it still presents some unique challenges.

One of these challenges is based on the fact that with the fast drilling rate achieved in shale formations, the drill bit can encounter interbedded formations more quickly, at a higher rate of energy. This situation can present challenges in terms of bit durability. In order for the bit to successfully perform in these unconventional conditions, it is critical to have the right bit, teamed with the right cutters, along with good bit hydraulics. Using a bit that is able to achieve higher performance has an added benefit, since during drilling, there is less stress on bottom hole assembly and mud motor components.

Ulterra's SplitBlade™ technology has been achieving record results in shale and unconventional applications, on both rotary steerable and mud motor jobs. Due to SplitBlade's improved steerability and hydraulics, the drill bit retains good working condition for longer, which in turn helps the rest of the drill string run optimally. When the interval (or the end of the drilling section) is reached, there is less wear on the bit.

On a vertical curve lateral (VCL) drilled recently in the Eagle Ford, a long unconventional well was drilled with one bit. An 8.75 in. SPL616 drilled over 19 000 ft at an ROP of 155 ft/hr, setting an Eagle Ford 8.75 in. single run footage record.

PDC TECHNOLOGY

VAREL – DR. MICHAEL CHIU

Cuttings volume, formation types, and rig pressure limitations can drastically impair PDC bit hydraulic performance. Resolving this longstanding challenge typically requires an unattractive tradeoff between rig requirements and bit hydraulics. However, poor bit hydraulics reduces cooling, cleaning, and cuttings evacuation, which results in plugged nozzles, bit balling, coring, and other issues that reduce drilling efficiency and bit life. The quandary is compounded by softer lithologies, such as clays and shales, long laterals, and downhole motors.

In efforts to address the challenge, the industry has experimented with a wide variety of bit modifications, including nozzle length and size, pulsating jet nozzles, lateral jets set into the blades, larger junk slot area face volume, and hydraulic horsepower. These approaches have generally met with limited success.

Varel Oil & Gas Drill Bits is using an advanced hydraulics program to inform the application of a set of design characteristics including proprietary curved nozzles and webbed blades. Bits optimised using the HYDRA hydraulics optimisation program are significantly improving ROP and footage in applications long recognised as a problem for PDC bits - without affecting rig hydraulics.

The HYDRA programme is based on in-depth computational fluid dynamics studies, which contribute to a better understanding of the complex interaction between the various design elements that enables bit characteristics to be optimised for very specific applications.

In this optimisation process, the curved nozzles direct fluid flow to the cutter surface to improve cleaning and cooling. The nozzles improve bit stability and reduce formation erosion by limiting the fluid stream's impact on the formation, reducing coring and other problems to extend bit life and drill longer runs.

Webbed blades block fluid flow to adjacent junk slots to prevent cuttings recirculation. The configuration also eliminates fluid entrainment by adjacent nozzles to maximise nozzle efficiency. The unique junk slot geometry results in more efficient cleaning for greater cuttings removal and volume.

In the Permian Basin, HYDRA-optimised bits have significantly improved footage and ROP. For example, the interbedded clays, carbonates, limestones, and sandstones encountered in a New Mexico drilling programme make bit hydraulics central to efficient drilling. The operators' fastest one-BHA run to TD was achieved with an optimised bit that drilled a 7001 ft vertical section at 133 ft/hr compared an offset average of only 6579 ft drilled at 106 ft/hr.

In Texas, the Wolfcamp formation's interbedded shale, limestone, and sand cause coring, plugged nozzles, and bit balling. Four bits are typically required to drill the lateral section. Hydraulic optimisation cut the number of bits in half, and drilled 8% more footage at an 8.5% higher ROP compared to standard PDC bits used in offsets.

A single hydraulically optimised PDC bit also improved lateral drilling in the upper Wolfcamp, where downhole tool and motor failure is a concern. When the BHA was tripped for a tool failure, the same bit was run in the hole on the second assembly. The bit drilled a total 7724 ft. in 65.75 hours for a ROP of 117.5 ft/hr. The results marked a 58% increase in ROP versus the best offset, and a 96% increase in footage drilled.

ABRASION/WEAR RESISTANCE

ULTERRA – CHRIS GOOCH

In difficult drilling environments - featuring hard rock, transition zones, and highly interbedded lithologies - abrasion can be a factor that limits drill bit performance. Reaching increasingly difficult drilling targets in these challenging environments requires the drill bit to withstand higher drilling forces, particularly increased weight-on-bit (WOB). The bit must also incorporate an overall level of durability, ensuring that it can accommodate the vibration and wear factors associated with the drilling process.

Ulterra's XP™ bits are designed and manufactured for these demanding drilling environments, to ensure that the bit is never the performance limiter. The focus of XP technology is on making the bit as durable as possible, to maximise its structural integrity and stability.

Along with a bit body designed to ensure structural integrity, Ulterra XP bits are force-balanced to enhance stability. Through the application of specific, premium, abrasion resistant PDC cutters – and the positioning of the cutters to reduce tangential overload – XP bits deliver improved durability, allowing operators to increase drilling performance while pushing operational parameters.

The design of XP allows the use of greater WOB in even the most challenging drilling environments. These bits are capable of achieving high ROP rates through the toughest hard rock sections, with less wear on the bit. Additionally, TuffCast™ materials enhancement technology can be added in order to combat abrasion without sacrificing junk slot areas or blade strength.

HYBRID BIT DESIGN

BHGE – STEFANI REED

Hybrid drill bits, which pair roller cone and fixed cutter elements are proven to reduce torque fluctuations and improve tool face control in difficult curves and interbedded formations.

BHGE's Kymera Mach 4 hybrid drill bit represents the latest generation of hybrid technology. The new hybrid drill bit incorporates a number of design features that deliver improved performance, durability, and subsequent dull condition compared to previous generations of hybrid bits.

Designs targeted for hard rock applications include a roller cone with a pointed nose like that of a traditional roller cone bit. The pointed nose's tungsten carbide insert (TCI) cutting elements pre-fracture the formation in the middle of the wellbore before the bit's innermost PDC elements engage the rock. The cone-to-centre design of the new hybrid bit provides a dual-cutting action through the entire bit profile, delivering a more durable cutting structure that improves ROP while preventing core outs.

The Kymera Mach 4 hybrid bit was recently deployed in China. One of the first wells was drilled into an igneous rock formation with a true vertical depth of 3500 to 3700 m (11 483 to 12 139 ft) and UCS of 20 - 25 ksi. The operator estimated that it would take 80 days for a conventional hybrid bit to reach total depth, with 20 runs required to finish an 8 ½ in. section.

The new hybrid bit finished the 8 ½ in. section in only six runs. It also doubled the average ROP and distance drilled compared to earlier hybrid bit designs, setting a bit record for both ROP and footage in the block. The new bit also saved the operator 50 days off the original well construction plan.

BOOSTING ROP

ULTERRA – CHRIS GOOCH

Achieving high ROP targets is the result of the entire drilling system functioning properly. The drill bit, drill pipe, bottom hole assembly, drilling fluid, and steering mechanism all must work together. Equipment, overall setup, and people factors are all relevant to getting the best performance.

In the case of the drill bit, speed is always a priority, yet the speed of drilling must be balanced with the bit's ability to reach its desired interval depth. Minimising the overall time required to reach TD is the key. It is about saving rig time, helping operators work efficiently, and getting the well into production as quickly as possible. It is a fact that 'sharp bits drill faster', but there are other factors at play. If a bit is smooth and stable – drilling in an efficient manner – it will drill fast, be more resistant to damage, and be able to deliver maximum performance. The first step is to choose a bit that is suitable for the application, given all the technical challenges and performance limitations. Cutter counts and placements are analysed to be sure the depth of cut will be as good as it can be, all based on the bit's ability to make the distance.

In any application, there will be some parameters or factors that define the upper limit of ROP performance. These factors can include available pump pressure, torque and drag, and available weight at the drill bit. While selecting the right technology, it is important to analyse the limits present and apply the correct technology to help mitigate any limiters to performance.

The smooth and stable drilling of Ulterra's CounterForce® bit technology results in higher ROP. This technology is focused on harnessing the forces that cause vibration and using them to increase drilling efficiency. Following its introduction in 2013, CounterForce bits have successfully drilled more than 100 million ft, and 80% of the bits in the Permian today are backed by CounterForce technology. In addition, Ulterra's SplitBlade™ helps to eliminate lateral vibration at the bit through better hydraulics and improved steerability. This bit design is also setting new ROP records in a wide variety of formations. With these recent advances, fewer compromises are needed in order to hit ROP targets.