AT THE CUTTING EDGE

Aron Deen and Casey Kitagawa, Ulterra Drilling Technologies, Barry Schneider and Gary G. King, Shell, explain how new advances in PDC bit construction and design are helping to cut drilling costs in the Marcellus Shale.

A new-generation PDC bit design, which makes optimal use of available weight on bit (WOB) to accentuate cutter engagement with the formation, is delivering appreciable increases in both footage drilled and penetration rates in the high-angle curves and longer laterals typical of Marcellus Shale wells.

The durability of the design methodology is reflected in comparable per-run footage increases averaging 36%, with overall rates of penetration (ROP) roughly 52% faster than standard PDC bits. Accordingly, combining longer bit life and higher ROP with enhanced toolface control has translated to estimated cost-per-foot savings amounting to nearly US$ 57 000 per run, based on contemporary Marcellus spread rates.

Fundamentally, one of the key contributors to the improved performance and the primary differentiator of the FastBack™ steel body PDC bit design is the specialised geometry, which is designed to enhance the delivery of mechanic specific energy (MSE) into the rock. The capacity to divert more energy into actually failing rock is a function of the bit's streamlined blade configuration, which in a sweeping

Figure 1. *FastBack Technology puts the cutters deep into formation to help increase overall ROP and reduce cost-per-foot.*

departure from traditional PDC bit designs, features a minimalist approach to supporting the cutters. In other words, the smaller profile diverts energy directly to the diamond cutting surfaces and into the formation. In the larger bodies intrinsic of conventional steel or matrix PDC bit designs, the blade surfaces absorb a considerable share of applied weight, thus putting the brakes on cost-effective ROP and overall drilling efficiency. Moreover, the slimmed down blade configuration likewise enlarges the junk slot area, optimising hydraulics for highly effective hole cleaning, even in extreme gumbo and swelling shale environments.

The new blade top geometry allowed Ulterra to simultaneously increase both potential top-end ROP and durability. Despite making the switch to a 13 mm cutter from a 16 mm cutter, the company was able to increase cutter exposure by 66%. This additional exposure significantly increased the potential ROP of the bit while the additional cutters increased durability of the shoulder, ensuring the bit would maintain the additional ROP throughout the run. Complementing the novel cutter configuration is a specially formulated and applied hard facing material to resist erosion on the bit surface without compromising tensile strength, a prevailing issue in high-speed directional drilling programmes.

While the advanced PDC bit design has been employed in many applications and downhole environments throughout North America, the genesis of the new concept can be traced to the Marcellus Shale where challenging well trajectories often target intermittently hard and abrasive formations.

Reinventing PDC bit designs

A major operator had used the previous generation Ulterra PDC bit to drill more than 80% of the curve and laterals in its Marcellus drilling campaign, where it generated top-end instantaneous ROP of up to 320 ft/hr while rotating. While delivering good drilling rates, the earlier PDC bit type had reached a performance ceiling, prompting the operator to request a directional bit that could increase instantaneous ROP to around 500 ft/hr, while also effectively building the curve and holding azimuth during rotation to reduce walking tendencies in the longer laterals. Specifically, the prototypical directional bit would couple high instantaneous drilling rates with the capacity to build angle and exhibit enhanced tracking and response to steering inputs in the horizontal interval, thereby increasing overall ROP and footage drilled.

The operator request spurred a wholesale re-evaluation of conventional steel body PDC bit design protocol, especially for the longer laterals intrinsic of the Marcellus and other shale plays. The primary challenge for design engineers was to overcome the ROP restrictions that traditionally accompanied the proportionate increases in the WOB required for drilling longer horizontal sections. With conventional PDC bit designs, much of the additional weight is transferred to the drillstring where it is manifested in the form of increased torque and drag. Consequently, maximising the transfer of weight and torque directly to the toolface would produce a directional PDC bit that would conceivably drill faster, longer and exhibit enhanced steerability.

Simulations of standard PDC bit designs confirmed that when ROP reached a certain point, weight transmission to the bit was largely inefficient in drilling new hole, as a considerable portion of the blades simultaneously were being buried in the formation. Therefore energy that could be directed to drilling was being wasted by pushing unproductive blade surfaces, whose sole function ostensibly is to hold the cutters in place rather than serve as *de facto* bearing surfaces. In so doing, the blades and bit body consume hole-producing weight that otherwise could be transmitted to the cutters.

Clearly, with standard PDC bit designs, conventional material and manufacturing limitations precluded the simple extension of the cutter projections to increase drilling rates and footage. Owing to this and other considerations, it was determined that the optimum approach was to completely transform the generally accepted platform for PDC bit design. Basically, the primary criteria of the re-design were to ensure sufficient material strength for securing the cutters, while at the same time lessening the energy-draining impact of the blades.

The ensuing development programme and subsequent testing resulted in a total overhaul of the design framework for PDC bits and, for the first time, reduced the performance-inhibitive engagement of the bit body, thereby transmitting once-wasted energy straightaway to the cutters for making new hole. In essence, the design strategy removes the blades from the actual well construction equation.

The new design methodology creates PDC bits without the limitations of material weaknesses and instead strategically aligns the individual components to seamlessly capitalise on their individual strengths. The centrepiece of the technology is the inclusion of thinner blades that, nonetheless, are roughly four times stronger than those of conventional PDC bit designs. These thinner, yet more durable, blades clear the way for steel body PDC bits to be designed to maximise the ROP potential from every size of cutter. The ability to significantly raise the traditional ROP ceiling associated with cutter size reduces conflicting durability tradeoffs based on cutter size and count. Despite the comparably leaner blades, and potentially even smaller cutters, exposure is optimised for high-speed drilling with up to 40% less weight than that required of a standard PDC bit. Basically, increasing the cutter exposure translates into less formation rubbing the bit during high-ROP drilling applications. Moreover, the customised selection and application of the premium diamond cutters is bolstered through a state-of-the-art cutter testing initiative.

Hand-in-hand with the increased exposure, the novel layout enlarges the junk slot area some 20% compared to conventional steel-body PDC bits and up to 40% larger than their matrix counterparts. Even under extreme ROP, the geometrical configuration with its more liberal junk slot area prevents the micro balling that can quickly build up on the tops of blades contacting the formation. Essentially, the drilling fluid flows more efficiently through the cutters and, because of the increased exposure, maintains a cleaner hole bottom for continuous cuttings evacuation.

The steel bit body itself is fabricated with high-strength material that poses no restrictions on either cutting action or solids evacuation. To eliminate erosion and maintain overall integrity of the bit body and cutter pockets, the newly engineered PDC bits are specially overlaid with proprietary tungsten carbide alloy hard facing. Unlike typical hard facing applications, the newly engineered material has no negative impact on either body strength or directional performance.

The energy-centric design framework has resulted in an evolutionary steel-body PDC bit that consistently allows operators to drill more footage, more aggressively and maintain improved toolface control and steerability in horizontal zones. The performance benefits of the breakthrough in PDC bit performance is clearly illustrated in the curve and lateral sections of Marcellus Shale wells.

Performance recap

Normally, the curve and lateral sections of Pennsylvania Marcellus Shale horizontal wells penetrate the Tully limestone and the underlying Hamilton, Burkett and Upper Marcellus shales that overlay the targeted Lower Marcellus pay zone. Occasionally, well trajectories require drilling troublesome Cherry Valley limestone stringers while building the curve, or drilling the lateral where historically PDC bits have sustained severe impact damage to the point of coring out. Further, operators frequently must contend with the difficult transition from the interbedded chert stringers in the extremely hard Onondaga limestone below the Marcellus, which has proven equally detrimental to PDC bit longevity and performance.

Representative Marcellus wells are batch drilled on pads averaging four to six wells, with programmed laterals that have been extended sequentially from 4000 ft to 7000 ft. Typical curve build rates range from 8 to 10˚/100 ft with turns of 60˚ to 120˚ commonplace in today's wells. Furthermore, owing to the melding of environmental limitations and downhole characteristics, Marcellus wells generally are drilled with invert emulsion synthetic-based mud (SBM) with densities ranging between 11.7 and 13 lb/gal.

An examination of the bit record dataset over a one-year period showed the operator drilling a cumulative 182 580 ft of Marcellus curve and lateral sections with earlier generation PDC bits in 2352 total hours at an average ROP of 76 ft/hr, thereby accumulating an aggregate 1863 ft over every 24 hour drilling period. By comparison, the later change to the new generation PDC bit resulted in the drilling of 92 929 ft of curve and lateral intervals in 990.7 hours for an average penetration rate of 93.8 ft/hr. Consequently, the new design allowed the operator to drill an average 2251 ft of new formation over 24 hours.

Cumulatively, the new PDC bit design has increased average per run footage drilled 36% to 1311 ft. When compared to offsets employing competitor PDC bits, the increased ROP with the new generation design, in turn resulted in 52% more daily footage drilled.

Assuming a US$ 48 000 daily spread rate, the improved drilling efficiencies saved the operator US$ 56 976 per run for an aggregate saving of just over US$ 1.08 million.