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Advances in Steel Tooth Technology Pushing PDC Out of GoM Applications

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Abstract

In spite of significant PDC encroachment into traditional roller-cone applications, steel tooth (ST) bits still drill approximately one-half of the total footage in the U.S. Gulf of Mexico (GoM). The PDC vs ST bit selection is largely driven by OBM/SBM vs WBM, respectively. Additionally, the ST's resistance to balling in WBM and its desirable steerability characteristics make it a viable tool in the GoM for the foreseeable future.

ST performance has increased significantly over the last decade due primarily to technical advances in life and reliability of both bearings and cutting structures. The improved bearings yield longer runs with reduced risk of failure. Increased tooth wear resistance from advanced hardfacing allows long hole sections at sustained ROP's. Despite these advances, the basic ST cutting structure has remained fundamentally unchanged for four decades.

R&D efforts from the 1990's convinced one manufacturer an extensive research effort was warranted to develop a new ST cutting structure that delivered substantial improvements in ROP without sacrificing durability. The result is a new High-Velocity Steel Tooth (HVST) bit with the industry's first significant new ST cutting structure arrangement in more than a decade. The patented pyramid-shaped tooth is a key element of the aggressive cutting structure and maintains a like-new condition longer before dulling. The new technology is having a beneficial impact on drilling economics in GoM by delivering unmatched ROP and greater footage than conventional ST bits.

An operator tested a new 9-7/8" HVST in a sand/shale section in GoM - Mississippi Canyon. The bit drilled 4,392ft at 55 ft/hr while holding 46º in 11ppg WBM. The new ROP is 10% faster than the 50 ft/hr benchmark set by a standard ST on an offset well from the same platform. Based on the initial success, the operator ran a second HVST with more aggressive operating parameters, drilling 4,392ft in one run at an average ROP of 73 ft/hr, 46% faster than the standard run. Drilling time was reduced by 24.5 hours saving the operator $139,000 USD. Additional case studies will be presented further documenting similar cost savings.

Introduction

With vast regions of the Gulf of Mexico (GoM) rapidly becoming mature provinces, operators are constantly looking for ways to systematically reduce the costs of drilling development wells, especially with improved technologies that deliver increased performance and decreased risk. Most of the offshore GoM wells drilled are directional, and drilling fluids with high mud weights (MW) are often required for well control purposes in the intermediate hole sections. The resulting extremely high bottomhole pressures and sticky, balling shales make it difficult to increase bit rate of penetration (ROP). Operators strive to improve their drilling economics with increased ROP, maximized footage drilled per bit, and fewer bits to complete each section in order to reduce the number of trips and associated non-productive (flat) time.

While PDC bits continue to replace many traditional tungsten carbide insert (TCI) roller cone applications in medium hard to hard formation U.S. land drilling applications, steel tooth (ST) bits have maintained a relatively constant one-half of the total footage drilled in the U.S. GoM for several years. This is believed to be due to a number of factors. One of the primary considerations is mud type: oil-based muds (OBM) and synthetic-based muds (SBM) enable PDC bits to drill at relatively high ROP's in the sticky shales in the GoM without excessive bit balling, while ST bits drill well in the much less expensive water-based mud (WBM) systems. Another significant factor is that ST bits have continued to improve significantly over the last decade, primarily in bearing seal life and reliability, and cutting structure robustness and longevity.

Improved ST bits with a novel single energizer metal seal (SEMS) bearing were introduced to the U.S. GoM in 1998, and from there migrated to other drilling basins around the globe.[1-7] A step change in bit life and reliability was realized over predecessor elastomer sealed tricone bits, with operators routinely achieving runs up to twice as long, particularly at higher RPM's (175 – 275 RPM). The new SEMS bits proved to maintain their typical bit life and reliability at elevated rotary speeds, while elastomer sealed bits tend to experience reduced seal life due to accelerated seal wear rates when rotary speeds exceed 200 RPM. Another step change improvement in bit life and seal reliability was realized in 2005, when a second generation single energizer metal seal system (SEMS2) was introduced to the market.[8,9] These long life, high reliability, high rpm-compatible sealed bearing systems provide suitable platforms from which to launch improved ST bits for the GoM market.

Enhanced ST cutting structures were introduced to complement the SEMS bearing in 2001 (see Figure 1). The new ST cutting structure features provided longer tooth life by virtue of improved tooth wear resistance, and reduced tooth breakage in service.[10-13] The ST cutting structure enhancements included: 1) new hardfacing materials with a step increase in wear resistance, applied with an increased hardfacing deposit thickness on the tooth crests, 2) highly wear resistant cone heel/gauge surfaces to resist abrasive gauge wear and gauge rounding in service, and to reduce the fluid erosion often experienced in this area of the cone, 3) full spearpoint protection to reduce erosion and abrasion that may lead to coring in long ST bit runs, particularly when centerjet nozzles are utilized, and 4) proprietary beads of hardfacing strategically applied to the corners of the inner and heel row tooth flanks to resist breakdown in these critical areas. This comprehensive set of enhanced ST cutting structure features, when combined with the new SEMS bearing, provided unequaled performance in many basins around the world, including the GOM.[3,14] It is noteworthy, however, that the basic cutting structure design – the number of rows of teeth, the number of teeth within rows, the tooth projections, the cone offset, etc. – have gone largely unchanged for the last 50 years (see Figure 1). This translated into similar bit ROP's for bits in the new condition, and maintained ROP's over longer intervals, since tooth wear in service was reduced with the material and design improvements; however, these were not faster overall designs.

Other bit manufacturers also tested new ST cutting structure designs in the GoM from 2002 – 2004, most of these new bits maintained similar cone offset, tooth projections and row counts, with attempts made to balance the cutting structure through variations in tooth counts and by skewing the teeth within rows. Skewed teeth with modified tooth counts may help to produce smoother running bits with somewhat reduced tooth wear rates, but overall ROP's were not improved significantly. While a properly oriented skewed tooth crest may experience less wear in service due to contacting the formation more squarely than a conventional radial tooth, the skewed tooth will also provide less action on bottom since it somewhat negates the cone offset action, thus reducing the contribution of cone offset to bit ROP. Skewed teeth can also be problematic in sticky shales, since they tend to ball up more readily than better-vented radial teeth. These bits did not deliver a large improvement in the drilling economics of the U.S. GoM.

Drilling research was initiated in 2003 by one manufacturer seeking increased ST bit drilling rates through innovative cutting structure arrangements. Various novel design approaches were evaluated in the laboratory with an industry leading high pressure bottomhole drilling simulator.[15] The most promising of the new arrangements was then engineered for manufacturability, in part by developing improved welding techniques for applying hardfacing to the cones. Recently developed design and material improvements for better gauge holding were also incorporated in the new design, along with an all new shirttail protection scheme. After extensive field testing with resulting iterative design and manufacturing improvements, the new High-Velocity Steel Tooth (HVST) bit is now being exploited by numerous operators in the U.S. GoM. Several case studies will be presented to document the cost savings being generated by these new faster drilling, longer lasting ST bits.

Description of GOM Drilling Application

GoM exploration and development programs are taking wells to ever greater water depths and measured depths. The increased service life and reliability of modern rotary steerable systems and high-end motor assemblies allows them to successfully drill long, complex well paths, which ratchets up the requirements on all bit types. The overall well economics often require the use of water-based muds rather than costlier oil- or synthetic-based muds. ST bits enjoy distinct advantages over PDC bits in WBM due to their lower initial price, their ability to recover from bit balling situations, their steerability, and their high build-up rate potential. The current high offshore rig day rates can only be offset by drilling wells in fewer total hours, which means higher drilling rates and less flat time are required. The drive to improve drilling economics in the GOM demands that individual bits drill farther and faster than in previous years. Drilling these challenging hole sections in fewer hours with fewer bits per section is the ever-present goal, until eventually all hole sections can become one-bit-sections. With this demand comes the need for step-changes in ST bit technology to meet the needs of the industry.

Typical GoM well programs include 8-1/2" hole sections in the 12,000 to 18,000 ft measured depth (MD) range, with mud weights (MW) ranging from 15 to 19 ppg due to well control considerations. The combination of high mud weights and great depths often results in very high bottomhole pressures. High bottomhole pressures effectively strengthen the sand and shale formations, which may aggravate bottom- and/or bit-balling tendencies, and increase the wear rate on the cutting structure. These factors tend to limit ST drilling rates and tooth life, and are difficult to overcome with simple operating parameter changes (WOB, RPM, flowrate, etc.). A HVST bit design that can drill faster without sacrificing bit durability or longevity could drive substantial savings in this complex and dynamic drilling environment.

ST Drilling Research

A research project was initiated in 2003 to significantly improve the ROP potential of 8-1/2" IADC Class 117 steel tooth SEMS bits run in the challenging U.S. GoM drilling application (as described above), without decreasing the bit's durability or longevity. A cross-functional product development team consisting of R&D scientists, product engineers, field engineers and manufacturing specialists was chartered to develop the new HVST bit. The team began by reviewing several novel ST design concepts that were studied in the mid 1990's, but never brought to market. Key insights were gleaned from the earlier research efforts and coupled with technology and captured knowledge from the last decade of successful ST bit designs.[16-18] Two 8-1/2" diameter prototype concept bits were designed and manufactured for preliminary laboratory drilling tests, and benchmarked against the current market leading ST bit. One of the two prototype bits appeared to have strong potential from both drilling performance and manufacturability perspectives, so it was selected for further development.

The new HVST design used pyramid shaped teeth in the inner rows, and chisel shaped heel rows with shorter crests than standard. Similar tooth projections and cone offset to the baseline bit were specified, but two more rows of teeth were added. The crest lengths of the pyramid shaped teeth are much less than conventional chisel shaped inner rows, this provided the room required for the additional rows of teeth. The pyramid teeth also provided room for designing wider spaces between the middle rows of teeth; this has been determined to be beneficial from an anti-balling standpoint. A new "anti-tracking row" concept was also developed whereby a middle row on one cone is given approximately twice the normal number of teeth in order to break up the large tracking buildups that often occur on conventional ST designs when the outer three or four rows of teeth start tracking together.

An offshoot of the HVST team developed a new ST bit with significantly increased wear resistance for drilling longer (or multiple) hole sections in highly abrasive drilling applications.[19] This team developed an improved gauge design which proved to hold gauge much longer, resist gauge rounding in service, and almost eliminate cone shell erosion between the heel and gauge teeth in the outer areas of the cones. An improved shirttail protection scheme was also developed by this subteam. The new gauge design and the new shirttail protection were both incorporated in the subject new HVST design since the wear life and durability of the new gauge and shirttail had already demonstrated a step increase in performance in extremely challenging drilling applications.

An extensive series of high pressure drilling simulator tests was conducted to compare the new prototypes to the standard production designs under various downhole conditions and rock types. Several test protocols were included in the test matrix:

- The "heavy mud deep GoM" test conditions included 14 ppg WBM, Catoosa shale and 6000 psi bottomhole pressure, with a broad range of WOB's and rotary speeds, to model both rotary and motor conditions. Another test parameter was hydraulic energy level, with tests run from low to relatively high HSI levels (0.7, 1.4, 2.4 & 4.4 HHP).
- The "deep land" drilling conditions included 9.5 ppg WBM, Mancos shale and 4000 psi bottomhole pressure, with similar operating parameter ranges per the above.
- The "fast surface" drilling conditions included 9.5 ppg WBM, Catoosa shale at 1000 psi bottomhole pressure, with similar operating parameter ranges per the above.

Figures 2 – 4 summarize the lab drilling test results:

- Figure 2 shows the drilling tests conducted under "Heavy Mud/Deep Hole" conditions – the dark blue bars are for the standard 117 bit, the light blue bars are the "standard + 30%" target ROP, and the red bars are for the HVST bit. The operating parameters were 60, 120 and 240 rpm, with WOB's from 15 to 45 klbs. The HVST bit's ROP exceeded the +30% target at all but one of the test conditions.
- Figure 3 shows line graphs for the Deep Land test results, the HVST bit's ROP exceeded the conventional 117 bit's ROP by 25% – 50%.
- Figure 4 shows line graphs for the Fast Surface Hole drilling conditions, the HVST bit's ROP exceeded the conventional 117 bit's ROP by 25% – 60%.

Several conclusions were drawn from this test series:

- The HVST bits drilled faster than the conventional 117 bits in both Mancos and Catoosa shales across the broad ranges of test conditions and operating parameters.
- All ST bits drill less efficiently at lighter WOB's due to the relatively low depths-of-cut and increased tracking under these conditions.
- The HVST ROP advantage appears to be greatest at a medium WOB of about 30,000 lb for an 8-1/2" bit, or 3500 lb per inch of bit diameter.
- Good hydraulics are required for the HVST to realize its full ROP advantage.

Based on these laboratory drilling test results, the team was confident the new HVST design would drill at high ROP in commercial field applications, yet the question remained: how durable and robust would the new design be? Could the conventional paradigm that a faster bit will necessarily be less durable be challenged?

New HVST Design Features

The new HVST cutting structure design was developed with specific features for high drilling rates, along with other specific design and metallurgical features for improved durability and long life:

- A new pyramid tooth shape was developed and subsequently patented, which became integral to the new HVST cutting structure design[12]. The as-welded, 4-sided pyramid tooth shape results in a near-conical appearance (see Figure 5). The hardfacing deposits on the tooth crest are relatively thick, and the hardfacing material used is very tough and wear resistant (see Figure 6). Conventional ST bits have chisel teeth with long crests (see Figure 1), which tend to wear and break down in service on the outer end of the crests due to the sliding and scraping cutting action produced by cone offset. The pyramid tooth diminishes this effect with its unique geometry. The effective chisel angles of the pyramid teeth are also relatively high, which provides a very strong base with resulting increased resistance to tooth breakage in service. Thus the pyramid tooth is an integral part of what allows the HVST bit to be both faster and more durable than conventional designs.
- Conventional IADC Class 117 ST bits in the 8-1/2” through 12-1/4” size range have 7 inner and heel rows of teeth. The new pyramid design includes 2 more rows of teeth for a total of 9 rows (see Figure 7). Furthermore, the spaces between the rows has been increased, which has been shown to allow drilled cuttings to flow out more efficiently; this results in reduced bit balling and higher ROP. This is a patent-pending feature.
- An “anti-tracking” high count row of teeth (see Figure 5) was positioned on the middle of the #2 cone to cut the large tracking buildups which would otherwise occur when the heel and middle rows of all three cones “index” or track together (as is common on conventional IADC Class 117 ST bits). The high count row has 13 teeth, which is about 50% more than the 8 or 9 teeth found on the corresponding row of a conventional ST design. This is also a patent-pending feature. Figure 8 compares the bottomhole patterns from laboratory simulator tests for 9-7/8” HVST vs. conventional ST bit designs, the contribution from the anti-tracking row is clearly evident. Reduced tracking results in a smoother running bit, less tooth crest wear, and reduced off-center running tendencies.
- Complete spearpoint coverage (see Figure 9) resists bit coring tendencies over long runs by reducing spearpoint erosion due to slurry abrasive flow, especially when centerjets are utilized (as is common in the GoM). This is a patented feature[13].
- Bi-metallic gauge hardfacing materials[17] are strategically placed on the heel teeth for specific functions (see Figure 10). The material along the gauge surface is formulated to reduce the effects of sliding abrasive wear that is encountered on the borehole wall. The material along the tooth crest and side surfaces is formulated to be tough and endure the impacting and gouge abrasion that the teeth encounter on the bottom hole. Key combinations of materials such as this provide for both long life and durability.
- Welded gauge trimmer pads were developed, as shown in Figure 11. Laboratory simulator tests and subsequent field tests showed that a cutting structure with trimming elements located between the heel teeth could help reduce gauge rounding and improve penetration rates without sacrificing durability. The bar trimmers remove the rock ribs formed on the borehole corner between the heel teeth. Eliminating the ribs helps the bit to more effectively cut the borehole corner by reducing both the work of the heel teeth and minimizing rounded gauge. The more efficient cutting mechanics and reduced gauge rounding both contribute to improved rates of penetration and increased gauge holding ability.
- A recessed groove in the cone gauge surface near the heel land is filled with highly wear resistant hardfacing (see Figure 11). This continuous ring of hard metal reduces both the rifle erosion effect from contact with the borehole wall and the fluid erosion that would otherwise occur (patent pending feature).
- The second generation single energizer metal face seal bearing package (SEMS2) was included on these new HVST bits (see Figure 12), for long life and high reliability in this high rotary speed drilling environment.[9] The SEMS2 bearing includes a 20% wider metal seal surface for increased capacity, and a proprietary new wear-resistant seal surface dramatically decreases the seal wear rate. The new seal surface also lowers the coefficient of friction for smooth, low-torque motion over many thousands of bit revolutions. The seal backup ring features a stress-engineered shape that extends its operating life and improves its ability to keep out debris, while redesigned energizer seal geometry improves sealing efficiency and ensures that the optimum face load is applied to the metal seal surfaces under all conditions.
- The shirttail area was reinforced with patented hardfacing material using an improved welding technique in the traditional shirttail/head OD hardfacing areas and in areas normally protected by TCI inserts (see Figure 13). In a standard ST bit, shirttail protection usually includes a bead of hardfacing welded on the leading and bottom edges of the head sections with TCI compacts inserted in the open areas of the head OD; however, in ultra abrasive applications, erosion of the base metal can cause the compacts to fall

out, while heat checking can cause the compacts to break or wear rapidly, reducing their effectiveness. The new shirttail has a large portion of the head OD covered with hardfacing to improve the shirttail effectiveness. A diagonal non-hardfaced area is used to channel material flow past the head OD.

Field Performance

Numerous HVST bits were run during 2006 in the U.S. GoM, as well as in Gulf Coast land operations in south Louisiana, south Texas, and east Texas. The following bit sizes have been tested to date: 8-1/2", 8-3/4", 9-7/8", 12-1/4" & 17-1/2". Test results have been very positive, with improved ROP's along with increased footage, decreased tooth wear, and strong gauge holding ability. The new shirttails are also displaying improved longevity and durability. The following case studies will provide examples of the performance levels being achieved by the new HVST bits.

Case Study 1

Location: Mississippi Canyon, Offshore Louisiana
Formations: Interbedded sand and shale sequences
Challenge/Objective: Drill out 9-7/8" hole from 4,608 ft and drill to TD at 9,000 ft while holding 46° inclination in 11 ppg WBM. The previous offset well on the same platform made it to TD in one run by drilling 4225' in 84 hours at 50 fph with a conventional premium metal seal 117 ST bit, this established the benchmark. The objective was to drill the section at a higher overall ROP.

Results: The operator agreed to test one of the new 9-7/8" HVST bits in this application. Moderate operating parameters were used, and the first HVST bit run completed the section by drilling 4192' in 76 hours at 55 fph, for an average ROP increase of 10%. The operator decided to drill the following well with another HVST bit, this time more aggressive operating parameters were used. The 2nd HVST bit completed the section by drilling 4392' in 59.5 hours at 74 fph, which is 46% faster than the benchmark (see Figure 14). Total drilling time was reduced by 24.5 hours, saving the operator $139,000. Both dulls were in excellent condition, which further boosted the operator's confidence in the HVST bit (see Figure 15).

Case Study 2 Location: Calcasieu Parish, LA
Formations: Frio sands and Hackberry shale
Challenge/Objective: Drill out from 3,500' in WBM through the Frio sands and the plastic, sticky Hackberry shale in which standard ST bits and PDC bits often have low ROP's.
Results: The operator agreed to test a 12-1/4" HVST bit in this interval. The plan was to drill with the HVST bit down to 7,100' and then pull it to finish the section with a PDC bit; however, after observing the excellent ROP through the top of the Hackberry shale, the operator kept the HVST bit in the hole. The bit ended up drilling 4865' to a depth of 8,360' at 61 ft/hr, this was more than double the footage compared with the best offset run in the area (see Figure 16) for a total savings of $55,000. The dull grade was 2 1 WT A E I ER BHA (see Figure 17), with erosion to the nose rows.

Case Study 3
Location: Cameron Parish, Louisiana
Field: West Chalkley Area
Formations: Interbedded Sand and Shale
Challenge/Objective: The challenge was to drill a vertical section out from under surface casing to the next casing point at approximately 9000' depth with higher ROP and fewer bits than the offset, which required three IADC 115 ST bits.

Solution: Operator agreed to run the new 17-1/2" HVST bits on a trial basis. The bits also featured the SEMS2 metal seal bearing package. Two HVST bits completed the section with improved ROP's, saving 4 drilling days and one bit trip compared to the three bit offset well (see day curve in Figure 18), for a total savings of $170,000.

Conclusions

- The HVST bit drills significantly faster than conventional ST bits in typical U.S. GoM drilling applications.
- The HVST bit displays improved bit life, durability, and gauge holding ability, drilling longer sections with less overall tooth wear and gauge wear than conventional ST bits.
- Moderate WOB's and good hydraulics are required for the HVST bit to realize its full ROP advantage over conventional ST bits.
- The new full-hardfaced shirttail design provides improved shirttail protection which may translate into improved seal protection and longer bit life, particularly in directional drilling applications.
- The higher ROP and longer bit life of the new HVST bit results in substantial drilling cost and risk reductions by drilling entire hole sections in fewer rotating hours, increased footage drilled per bit, reduced flat time due to fewer bit trips, and fewer ST bits to purchase.
- The improved drilling economics realized with the new HVST bits should enable ST bits to continue drilling a large portion of the total footage in the U.S. GoM, despite continuous improvements in PDC bit performance.

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Figure 1 – Modern premium 9-7/8" IADC Class 117 ST Bit (left) vs. a 1957 era IADC Class 115 ST bit (right). Note both bits have similar row counts, tooth counts, tooth projection, cone offset, etc.

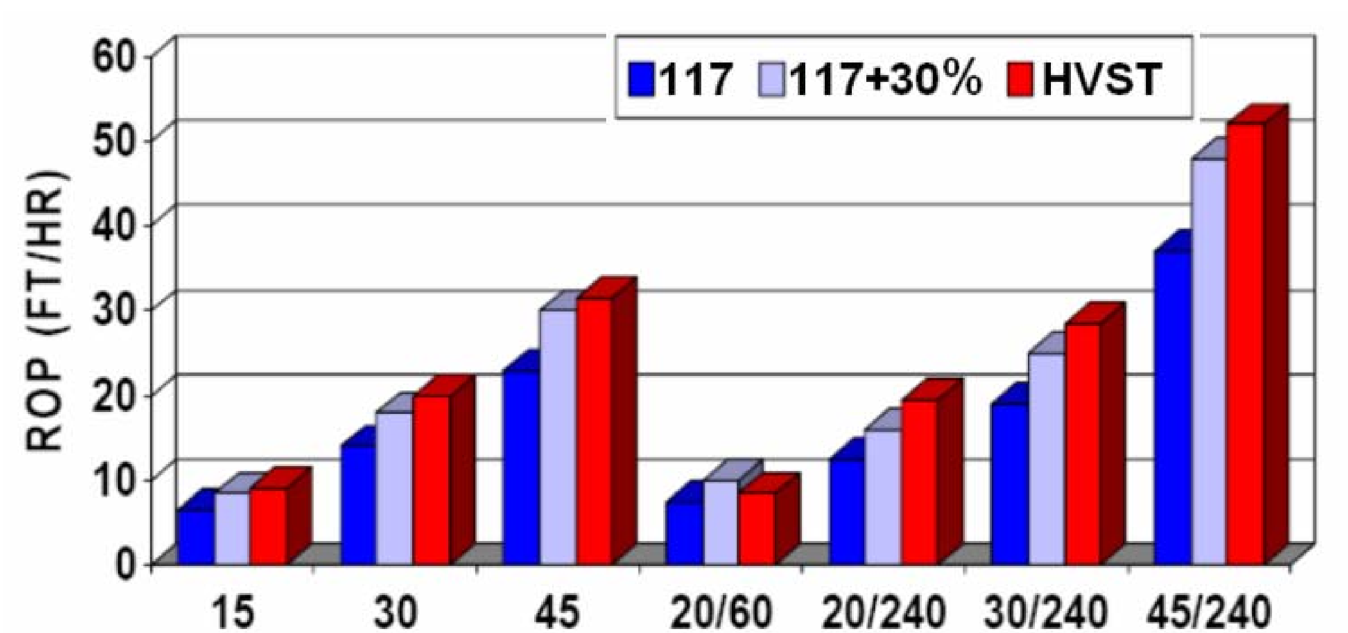


Figure 2 – Laboratory high pressure drilling simulator test results under "Heavy Mud/Deep Hole" test conditions: 8-3/4" bits, 6000 psi bottomhole pressure, 14 ppg WBM, Catoosa shale.
Operating parameters: 15, 30 & 45 klbs at 120 rpm for left side of graph;
WOB/RPM for 4 comparisons on right side of graph).

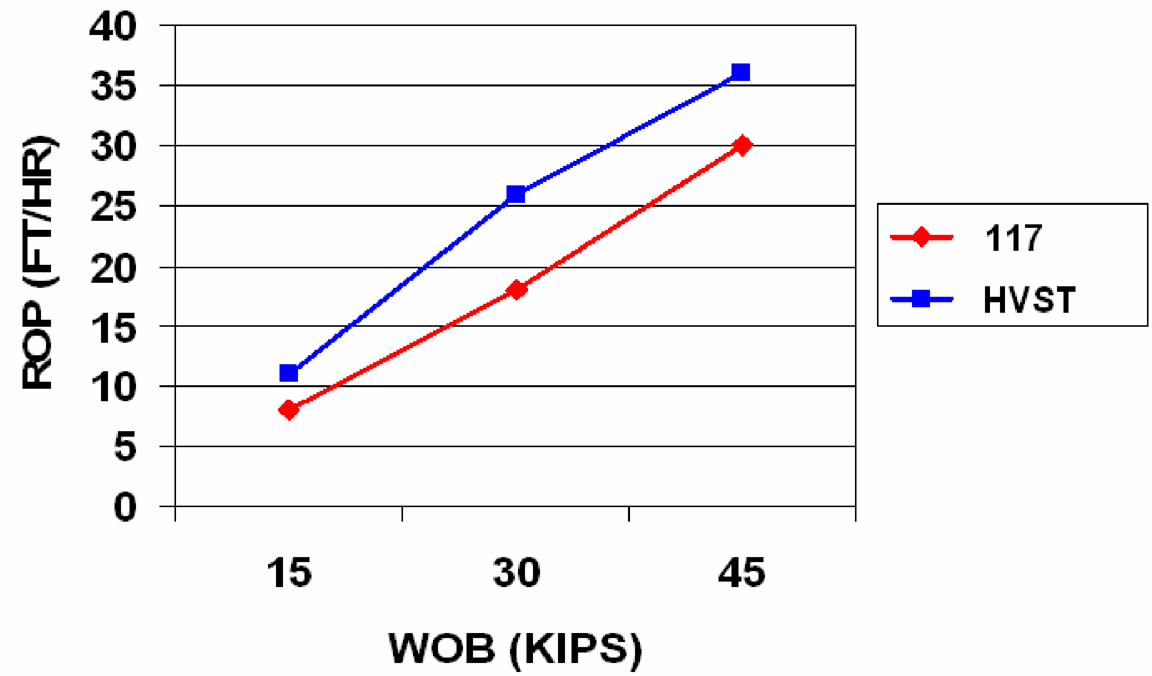


Figure 3 – Laboratory high pressure drilling simulator test results under "Deep Land" test conditions: 8-1/2" bits, 4000 psi bottomhole pressure, 9.5 ppg WBM, Mancos shale, 120 rpm.

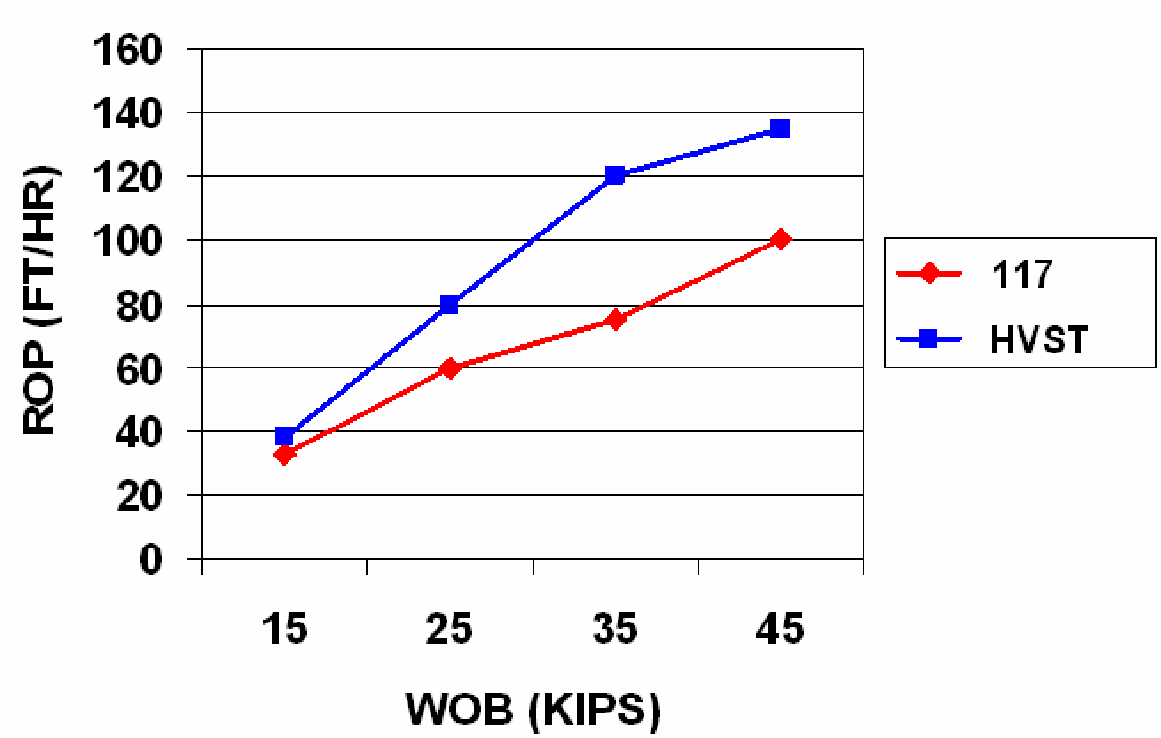


Figure 4 – Laboratory high pressure drilling simulator test results under "Fast Surface Hole" test conditions: 8-1/2" bits, 1000 psi bottomhole pressure, 9.5 ppg WBM, Catoosa shale, 120 rpm.

Figure 5 – Bottomhole view of the new 9-7/8" HVST bit.
Note the anti-tracking row identified by the arrow.

Figure 6 – Cross-section view of a Pyramid inner row tooth.
Note the thick hardfacing deposit on the tooth crest.

Figure 7 – Bottomhole view of the new 9-7/8" High Velocity Steel Tooth (HVST) bit (left) vs. the standard 117 bit (right).

Figure 8 – Laboratory bottomhole patterns for the 9-7/8" HVST bit (left) and the standard 117 bit (right). The arrow in the left photograph identifies the kerf being drilled by the HVST bit's anti-tracking row.

Figure 9 – Complete spearpoint coverage with hardfacing (shown by arrows).

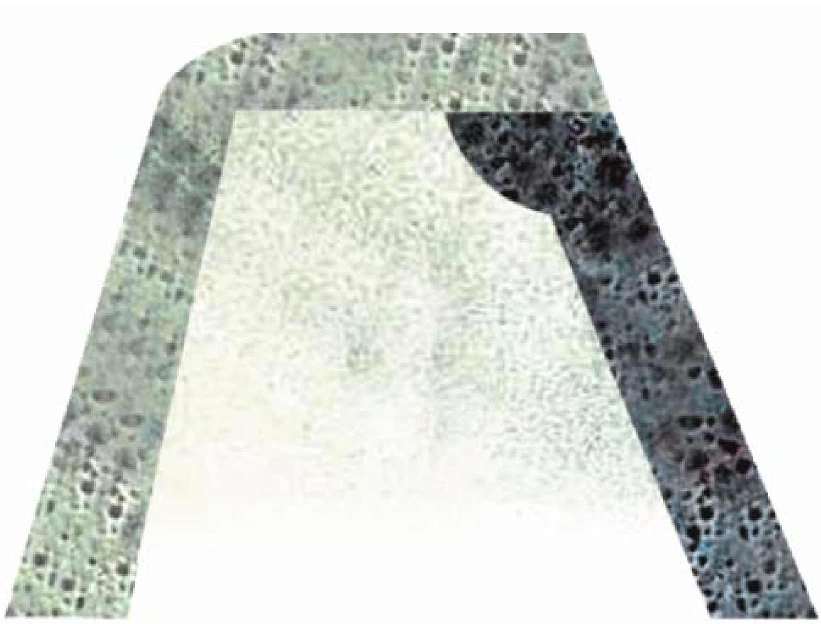


Figure 10 – Cross-section of a heel row tooth with bi-metallic gauge for wear resistance and tooth durability. The darker hardfacing is on the ground gauge surface.

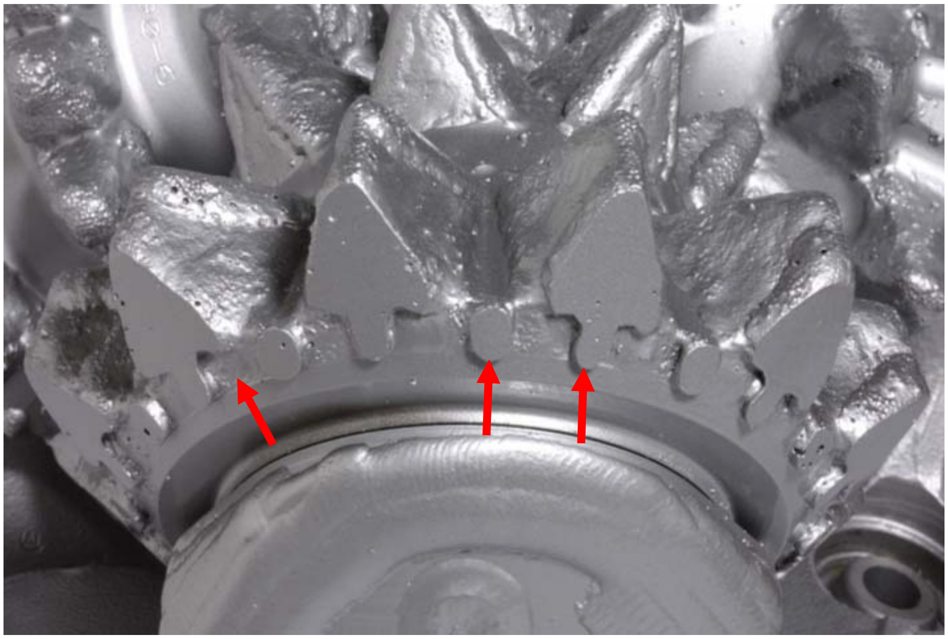


Figure 11 – Welded gauge trimmer pads, or bar trimmers, shown by two vertical arrows.
Note the continuous ring of hardfacing on the cone gauge surface between the bar trimmers, shown by the inclined arrow.

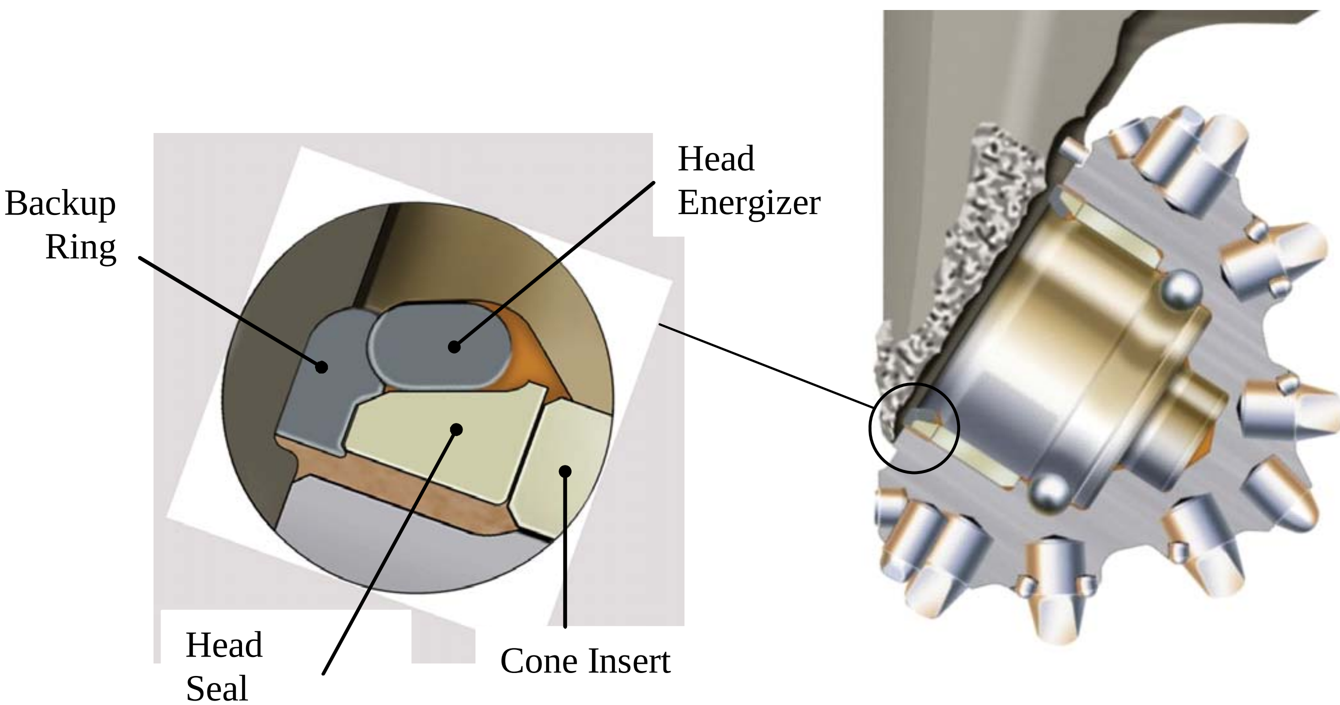


Figure 12 – Second generation single energizer metal seal bearing (SEMS2)
with enlarged view of seal package (circa 2005).

Figure 13 – Improved shirttail and leg hardfacing on 12-1/4” HVST bit reduces the damaging effects of hole-wall contact.

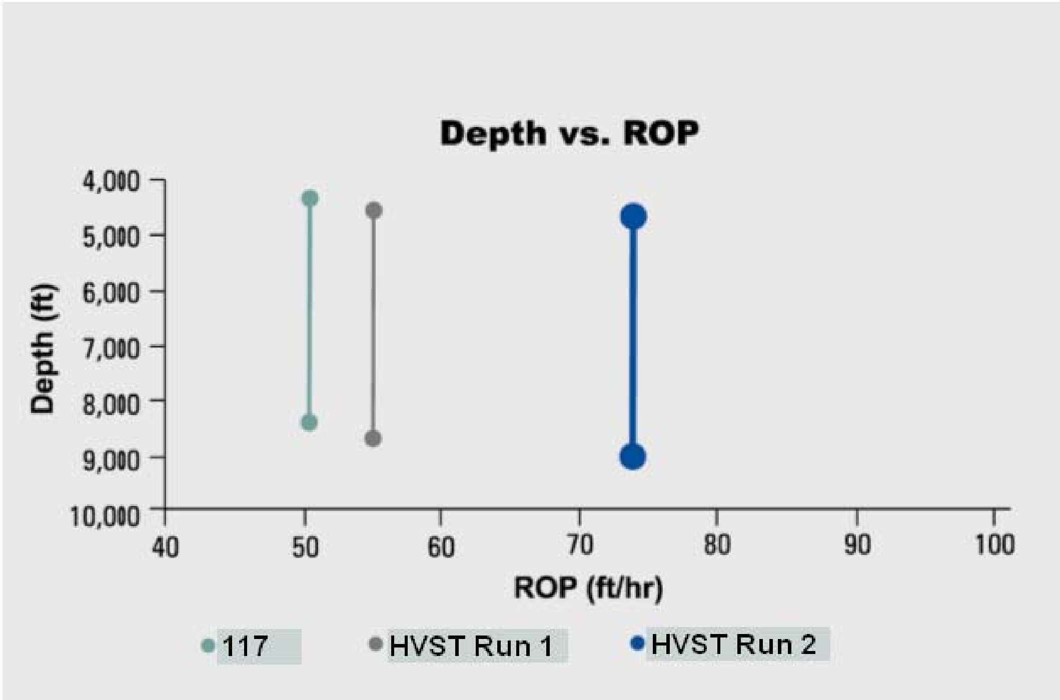


Figure 14 – 9-7/8” Bit run comparison of two HVST bit runs vs one conventional 117 ST bit offset.

Figure 15 – 9-7/8” HVST bit run #2 which achieved 74 fph section ROP.
The dull is in excellent condition after 4392’ of drilling with a dull grade was 1 1 WT A E I CT TD.

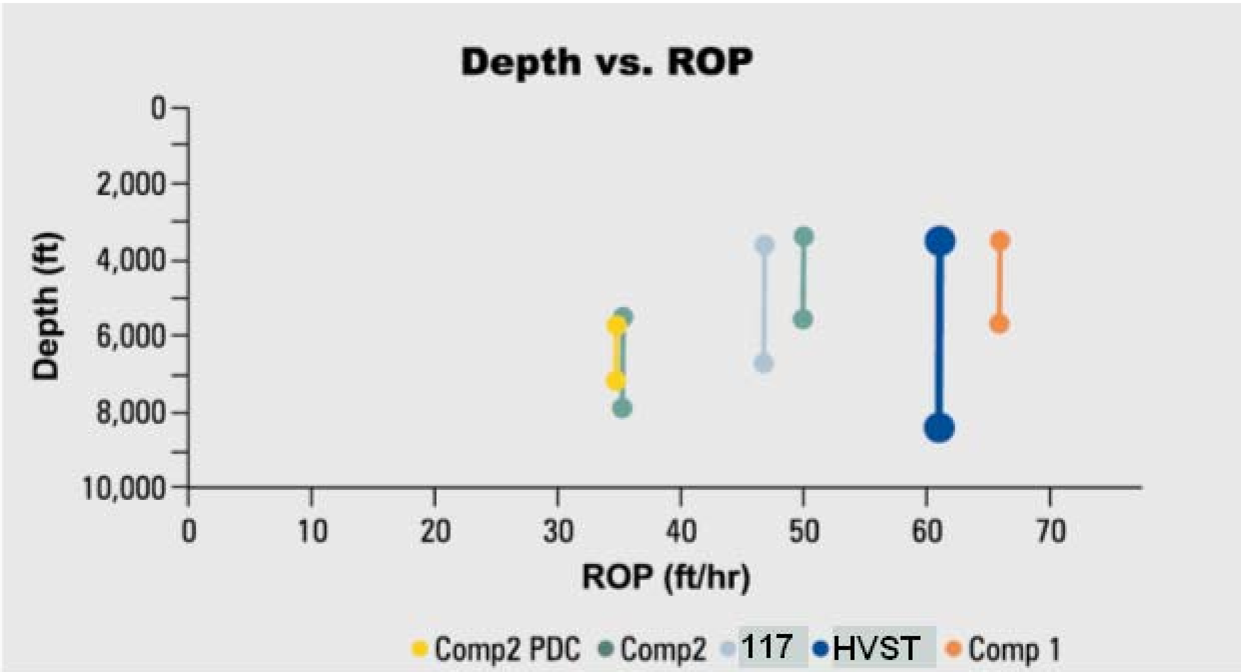
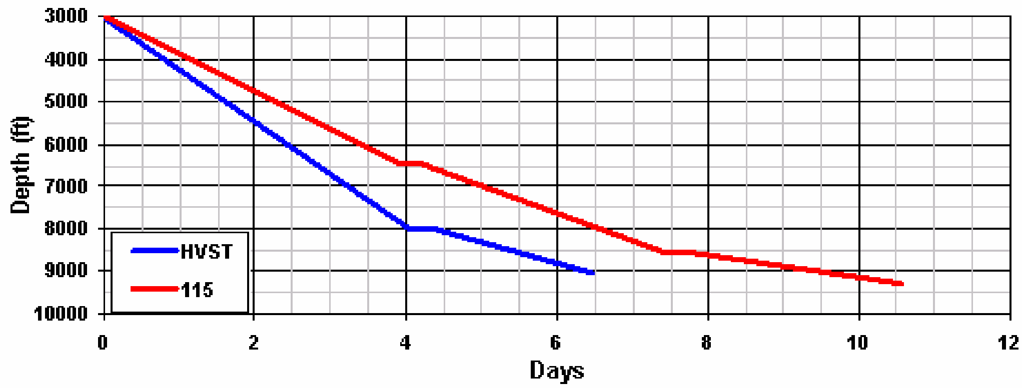


Figure 16 – 12-1/4" Bit run comparison of one HVST bit run vs several competitor tricone 117 ST bit offsets and one competitor PDC bit offset. The HVST bit more than doubled the footage of the best offset, and drilled faster than all the offsets that approached this depth range.

Figure 17 – 12-1/4" HVST dull in good condition after 4865' of drilling, the dull grade was 2 1 WT A E I ER BHA. Note the nose row erosion from extended service under high flowrates and a centerjet.



Performance Comparison

Size	Bit Type	Depth In	Depth Out	Footage	Hours	ROP
17-1/2”	HVST	3025	8003	4978	97.5	51.1
17-1/2”	HVST	8003	9035	1032	49.5	20.9
Casing Point to Casing Point			9035	6010	155	38.8

Offset Well

Size	Bit Type	Depth In	Depth Out	Footage	Hours	ROP
17-1/2”	115	3016	6435	3419	93.5	36.6
17-1/2”	115	6435	8566	2131	78.5	27.2
17-1/2”	115	8566	9287	721	66.5	10.8
Casing Point to Casing Point			9287	6271	253.5	24.7

Figure 18 – Day curves showing two HVST bits completing the 17-1/2” section vs. the offset section which required three IADC 115 ST bits. The test well saved 4 drilling days and the flat time associated with the extra bit trip.

Figure 19 – 17-1/2” HVST dull in good condition after 4978’ of drilling, the dull grade was 1 2 WT G E I ER HR.