DEVELOPMENT AND APPLICATION OF UNIQUE FIXED CUTTER BIT TECHNOLOGIES IN THE SPRABERRY FIELD OF WEST TEXAS

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ABSTRACT

Roller cone bits have long dominated the drilling in the Spraberry Field of West Texas. Experience and/or drilling log information have indicated that the formation is typically drilled with an insert type roller cone bit. Conical type insert bits are usually chosen because of the durability of their cutting structure. Typical intervals are from the surface casing to 9000 feet. The formations are usually drilled with premium journal bearing insert bits. Conical type insert bits, IADC 527Y and 537Y, are usually chosen because of the durability of their cutting structures in drilling the interbedded shale and limestone.

Development and application of a new type of fixed cutter bit, which is able to drill very efficiently through interbedded formations, incorporates new cutter technology with enhanced drillability, durability, and reduced vibration. Trials show an increase in penetration rates compared to the best roller cones run in the field.

INTRODUCTION

This paper presents the results of a project to develop effective fixed cutter bits, also known as polycrystalline diamond compact (PDC) bits, for specific applications in the Spraberry Field of West Texas. The inability of PDC bits to effectively drill hard rock because of various destructive forces generated has been well documented in previous papers [1,2,3,4]. Since the initial discovery well of the Spraberry Trend in the 1940's, the standard drilling practice was to use roller cone bits, exclusively, to drill the 7 7/8-in. hole section. Despite PDC technology improvements over the last two decades, roller cone bits were still dominant in Spraberry Trend applications because of poor PDC bit performance. This poor performance appeared to be caused by impact-damaged PDC cutters on these bits. It is theorized that this damage was caused by a variety of destructive forces generated when drilling the intermittent soft and hard stringers. Also, in general, the formations encountered in West Texas are older (Permian) and have higher compressive strengths compared to the Tertiary and Cretaceous formations drilled effectively with PDC bits in other areas [3, 4].

Early PDC bit design methodology, to overcome poor performance when drilling hard rock, has centered around two basic design principles. First, the anti-whirl design principle incorporated a low friction gage pad to minimize the effect of the backward whirl phenomenon of PDC bits [1,2]. According to this design principle, cutters were arranged on the face of the bit so that a net resultant radial force was directed toward a specific portion of the bit with less friction. In most cases, this was an oversized low-friction gage pad.

The second principle is the design and development of "force balanced", PDC bits [3, 4]. This principle was developed based on an understanding of the PDC bit dynamics and on the mechanism for cutter/rock interaction. Unlike an anti-whirl PDC bit, the cutters on a force balanced PDC bit were arranged so that new, resultant radial forces were minimized or balanced. The design of a force balanced bit allows for a higher density of cutters on gage than does the anti-whirl PDC bit, and higher density is more beneficial in harder rock drilling, The use of additional force balancing tools, such as tracking cutters and asymmetrical spiraled blades, improved bit performance significantly, further expanding the range of applications of PDC bits [3, 4].

However, more recent advances in PDC bit design and cutter technology have lead to the still greater increased drilling efficiencies outlined in this paper.

BACKGROUND

The overall goal of this project was to establish the practice of drilling one complete interval, from surface to TD, with one PDC bit. The project involved a joint development effort between multiple operators and the bit manufacturer. The direct benefit of the joint development effort was that significant savings would be realized by the operator because of reduced, or even eliminated, trips and reduced overall drilling time. Elimination of trips by drilling the entire section in one run would result in tremendous savings to the operator. Single-bit run intervals are also a factor in improving safety. Also, of additional benefit would be the reduction in drilling time as a direct result of higher rates of penetration. In addition, further developmental efforts were geared toward increasing bit repairability to allow additional runs with the same bit in a rental market, thus further reducing overall drilling costs. As a direct result of this project, even further drilling and performance improvements were achieved by the optimization of drilling parameters.

TARGET AREA

The target area for this project encompasses five major counties within which is located the Spraberry Trend. These are Martin, Midland, Glasscock, Upton, and Reagan counties.

LITHOLOGY

Well logs were utilized to investigate the lithology and to calculate rock compressive strengths (hardness). These logs helped to identify possible trouble spots that might prove to be detrimental to the PDC cutters. Historically, PDC cutters have been susceptible to cutter degradation due to impact and to heat damage due to abrasion. Generally, impact damage can occur when drilling through heterogeneous formation layers where successive layers vary in hardness. The forces which lead to impact damage can be generated by the BHA and can be either magnified or reduced by bit design.

The lithology in the top section of the interval, between a depth of 1,000 feet and 5,000 feet, is a shale and intermittent dolomite which has a compressive strength between 5 and 10 kpsi. The dolomites are the 'stringers' of interest and can be found layered within softer shale. Further into the interval, from about 5,000 feet to 7,650 feet, the formations are heterogeneous layers of limestone, dolomite and shale. This section is of soft to medium hardness with compressive strengths ranging from 10 kpsi up to hard stringers of 35 kpsi. Next, from about 7,650 feet down to 9,000 feet the formation consists of shaly carbonates of medium hardness from 10 kpsi up to 30 kpsi. Finally, below 10,000 feet depth, the formations are generally hard carbonates, primarily limestone and dolomites, with compressive strengths ranging from 25 kpsi up to as much as 40 kpsi. (Figure 1)

The major formations encountered in the Spraberry Trend are the Rustler, Yates, Grayburg, San Andreas, Upper and Lower Spraberry, and, sometimes, the Wolfcamp. All subject formations are Permian in age.

BASELINE PERFORMANCE

Since their introduction in the 1950's, roller cone insert bits have been used exclusively to drill the hard and abrasive limestone formations of West Texas [1]. In order to develop a baseline average for past Spraberry performance, a total of twenty-one (21) wells were utilized. Each of these wells was within the target area, and each used approximately 2 or 3 size 7 7/8-in. bits to drill the interval. The bit types used were IADC 527Y and 537Y insert bits with conical cutting structures. Bits were analyzed for footage, hours, and cost-per-foot for the section. The wells analyzed showed that a typical well averaged 38.3 ft/hr and took 9.7 days at an interval cost of $104,361. (Figure 2)

WELL PLAN

The 7 7/8-in. interval starts at an approximate depth of 450 feet and extends to a total depth (TD) of approximately 9,300 feet. All wells are vertical. Water based drilling fluid is used with relatively high solids. The bottom hole assembly (BHA) used was chosen in order to provide rigidity and stability in the well bore as well as optimum rate of penetration (ROP). The BHA generally consisted of one Tri-Drill collar, one square drill collar, and thirty 6-in. drill collars. The Tri-collar and square collar provided the rigidity to keep the bit engaged and the well bore straight without an increase in torque and drag, such as in a packed hole. Increased torque and drag could lead to a reduction in ROP and to an increase in cost per foot.

DEVELOPMENT

For initial trials a standard seven blade, ½-in. cutter (FM2745) bit was chosen. (Figure 3) Previous experience in other developmental areas has proven that this bit platform had sufficient durability to achieve maximum footage and eliminate one or more roller cone bits and trips. This initial PDC design utilized the force balanced features previously mentioned, asymmetrical spiraled blades with a heavier set gage cutter configuration.

The damage observed on the first runs included chipped and broken diamond layers and fractures in the cutter's carbide substrates. This damage was attributed to shock loading of the cutting structure, primarily located in the nose area, and thermal degradation of the diamond layer, primarily located in the shoulder cutters. In addition, there was heavy fluid/solids erosion to the matrix bodies.

The first 20 bits of this initial design (FM2745) drilled an average of 7,611 feet in 126.6 hours at an average rate of penetration of 60.1 ft/hr. A total of six of the 20 runs (30 %) made it to the target of 8,500 feet of depth or more.

In order to control the axial shock loading leading to cutter breakage, impact arrestors were added. Impact arrestors are protrusions from the bit body that are aligned directly behind a preceding PDC cutter. They are slightly under exposed from the cutter tip so that the impact arrestor rides in the track of the cutter. Because arrestors are the same matrix material as the bit body, they tend to wear at a higher rate than the cutter. The impact arrestor dampens the vibrating pattern of the bit by limiting the cutter's over-engagement.

While the impact arrestors were initially helpful in reducing the shock loading to the cutters, the matrix erosion limited the affects to the first run of the bit. Additional runs on repaired bits had similar shock loading and erosion as seen on the first trials. To retard this erosion, less expensive diamond cubes (TSP), were added to the impact arrestors. The added TSP reduced the matrix wear and added two to three additional runs per bit. (Figure 4) Further improvements to this design resulted in the use of diamond impregnated discs placed within each impact arrestor. This version (FM2745R) proved to be the most effective in reducing wear to the cutter pockets and impact arrestors. The use of these disks ensured that the beneficial action of the arrestor was present even on second, third and even further runs. (Figure 5)

STABILIZATION OF THE CUTTING STRUCTURE

PDC bit profile layouts generally have overlapping cutters to ensure no uncut formation. This type of cutter layout is more efficient since no more than 90% of a cutter tip is used to drill its particular area of bottom hole before adjacent cutters come into play. Various designs with individual cutter layout were tested. They provided excellent ROP in the shale, but runs were shorter due to cutter breakage from drilling the intermittent hard limestone stringers.

Weaver and others had introduced a cutting structure that was self-stabilizing [4]. This type of cutter layout, called "track set", eliminated the cutter overlap causing deep kerfs to be cut into the formation. Without the cutter overlap, the formation can extend up between the cutters, form concentric rings on the bottom hole, and increase cutter contact with the formation. The extended ridges cause the bit to lock into place and resist the lateral forces that lead to cutter breakage. It is also beneficial that two or more blades can have cutters that cut the same path on formation.

This type of cutter redundancy added durability to the bit, further reducing bit whirl and allowed for longer runs. The ROP lost by the less efficient drilling in the shale was made up in the harder limestone sections. (Figure 6)

CUTTER TECHNOLOGY

Initial trials with the industry standard cutter produced shorter runs with reduced ROP below 5,000 feet. The standard thin diamond table cutters would hold up better to the shock loading of the transitional drilling but would lose ROP due to cutter wear from the abrasive limestone/dolomite sections. Trials with thick diamond table cutters held up to the abrasive wear but would suffer catastrophic breakage due to the high residual stresses inherent to such cutter types.

Development of a new improved cutter ran parallel to PDC bit development in the Spraberry. Clayton and others discussed a new improved cutter, one better suited for hard rock drilling applications [7]. Development of the new cutter was the result of a better understanding of cutter failure mechanisms. As mentioned previously, abrasion and impact have been the two characteristics observed and studied in the past. Abrasion refers to the mechanically generated wear that occurs due to failure of the individual diamond crystals or of the diamond to diamond bond between those crystals. The diamond failure can be a result of mechanical loading or thermal degradation. Impact wear is a mechanical failure that occurs when forces are applied that overcome the strength of the bond between the crystals and/or the strength of the carbide of the PDC.

As a result of the extensive cutter research and development, Thermal Mechanical Integrity ™ qualified cutter analysis was identified as crucial to understanding a PDC cutter's failure. This failure is defined as a loss of diamond that occurs due to a combination of thermal degradation and force and is a measurement of toughness and wear as thermal degradation occurs. New testing capabilities were implemented that enabled cutter optimization of durability in both abrasive and hard inter-bedded formations and led to development of a new cutter more suitable to the tougher environments of hard rock drilling.

The resultant new cutter was shown to be 13.5 times more abrasion-resistant than the industry standard and 3.9 times that of the industry premium standard cutter, with no loss of impact resistance. The new Z3™ cutter is a high abrasion resistant cutter. (Figure 7)

FIELD APPLICATIONS

In addition to the bit development aspect described in this paper, significant improvements have been made by optimization of drilling parameters to the types formation drilled. All testing was done on rotary assembly. The rotary application allows for more abrupt changes in weight on bit and in RPM changes required for transitional drilling through interbedded formations. It was found that higher RPM, namely 75-80, could be run in the top of the hole down to around 5,000 feet with less than 20K WOB. As rock hardness increased below 5,000 feet, the RPM has to be reduced to 60-70 and WOB increased to 25K to optimize ROP and prolong bit life.

A total of 138 runs were made with the tested designs and drilled an average of 7,720 feet in 119.9 hours for an overall rate of penetration of 64.4 ft/hr. A total of 57 of the bits (41 %) made runs to the target depth of 8,500 feet or more. This performance compares favorably to 30% for the initial designs which reached the target depth.

A few of the significant results of the field testing of the features and innovations outlined in this paper are listed in the following case studies.

MIDLAND COUNTY

An FM2745, with first generation Z3 cutters and track set design, drilled 7,686 feet in 84.0 hours for an overall rate of penetration of 91.4 ft/hr. The run did not TD the well but the resultant cost-per-foot of $5.76 was well below the average $11.75 cost-per-foot of the 7 7/8-in. roller cone runs in the area. The dull bit graded a 3-3-CT-A-In gage.

REAGAN COUNTY

An FM2745 equipped with the new Z3 cutters, track set design with full impact arrestors, was able to drill 8,272 feet in 106.0 hours to TD at an average rate of 78.0 ft/hr. The dull graded a 3-2-CT-N-In gage. As a result of the outstanding ROP performance, the customer realized approximate savings of $44,000.

MIDLAND COUNTY

An FM2745R, track set design with Z3 cutters, run in Midland County, drilled 9,330 feet in 133.5 hours for an overall ROP of 69.9 ft/hr. This PDC run replaced three roller cone runs and two trips for a combined saving of over $45,000.

RECENT PERFORMANCE

During the last two months of 2004, data was obtained on 19 PDC bit runs in the target area. These bits were exclusively the FM2745R design with Z3 cutters and utilized optimized energy levels and running practices established throughout the test program. These bits averaged runs of 8,231 feet in 134.2 hours for an overall rate of penetration of 61.3 ft/hr. The rate of penetration is down slightly from the total average for all runs (64.4 ft/hr), but a total of 14 of the bits (74 %) reached the target depth of 8,500 feet or more. (Table 1)

An example of one of the better runs to date has been a run which recently occurred in Martin County and drilled the entire 7 7/8-in. interval to a depth of 9,220 feet in one run. This FM2745R drilled 8,860 feet in 126.5 hours for an average of 70 ft/hr. (Figure 8) The dull condition shows both impact and abrasive wear to some cutters in the nose to shoulder area of the bit. However, the wear was expected and is limited to PDC cutters that are easily replaced. Wear to the body has been kept to a minimum due to the use of impact arrestors set with impregnated diamond disks. (Figure 9)

CONCLUSIONS

A total of 21 wells using roller cones and 138 wells with PDC bit runs have been analyzed. The PDC bit runs incorporated a new type PDC cutter that extended the life of the bits in the hard transition drilling of the Spraberry Field of West Texas.

The features incorporated into this new series of bits includes:

- Force balanced cutting structure utilizing latest Energy Balanced bit design capabilities
- Impact arrestors, with TSP diamond or impregnated disk reinforcement, to dampen axial vibrations leading to cutter breakage
- A track set cutting structure to reduce lateral vibrations and add cutting structure durability through redundant cutter placement
- A new PDC cutter, Z3™, with significantly increased abrasion-resistance with no loss of impact-resistance, effectively drilling harder rock and hard transitions.

The consequence of this PDC development in the Spraberry is a PDC bit capable of drilling from surface to TD with one bit at an average ROP above 60 ft/hr. These improvements have resulted in savings of up to $40,000 per well to the customer.

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Table 1
Average Performance of all PDC Bits within Target Area

Type	**Quantity**	**Depth Out**	**Footage**	**Hours**	**ROP**	**% to Target**
FM2745	20	7943	7611	126.6	60.1	30%
FM2745 / FM2745R	138	8118	7720	119.9	64.4	41%
FM2745R	19	8709	8231	134.2	61.3	74%

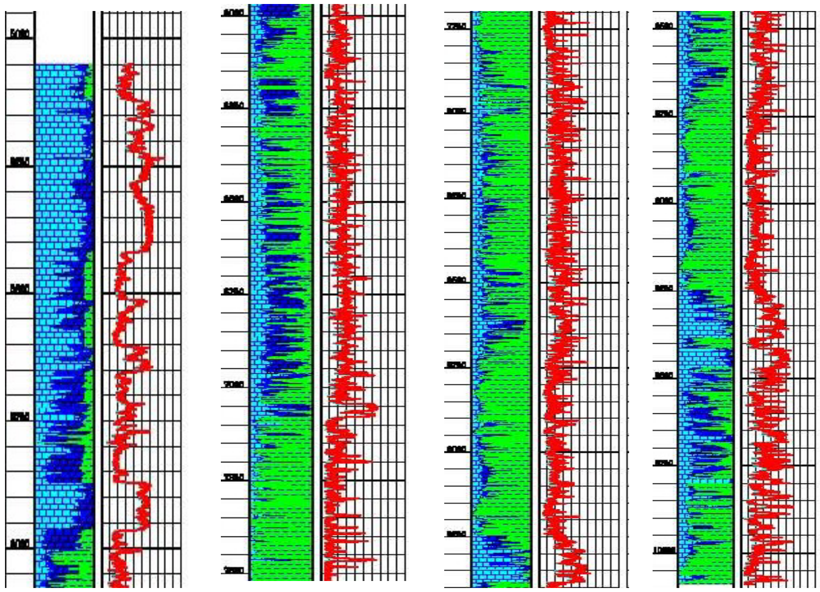


Figure 1 - Typical Spraberry Interval from 5000 ft to 10,000 ft. Compressive strength reading to the right on each with ranges from 0 psi to 50,000 psi.

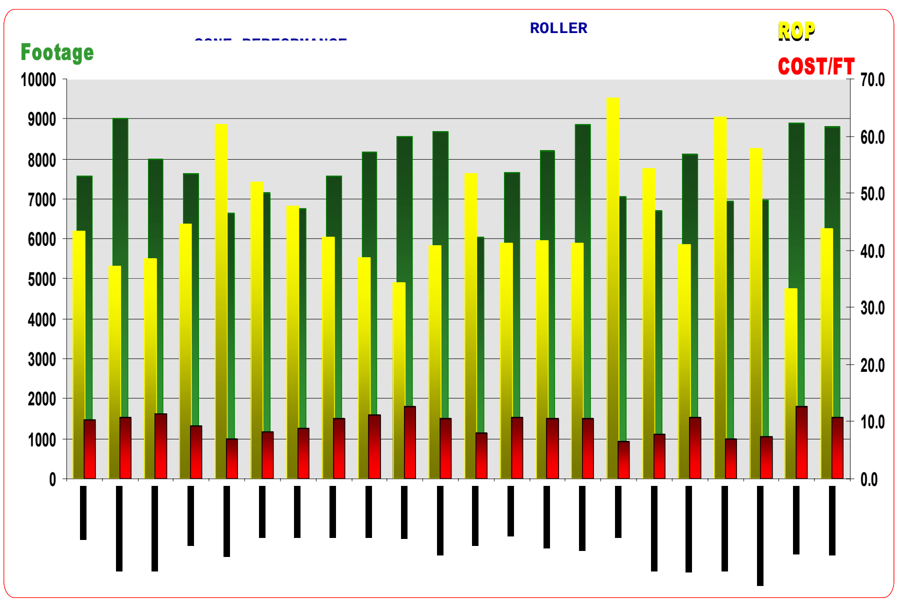
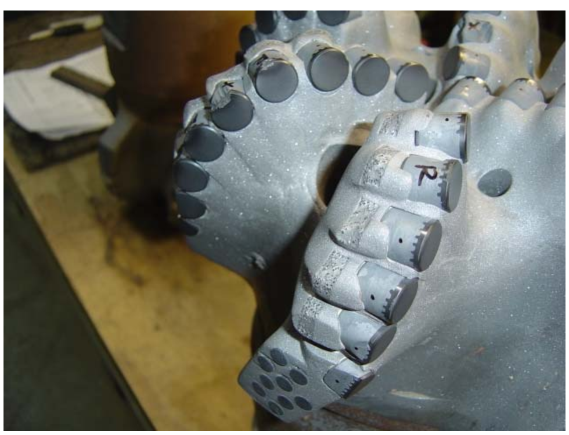


Figure 2 - Roller Cone Performance Averages for 21 Wells in the Spraberry Trend

Figure 3 – Initial PDC Bit Design – FM2745



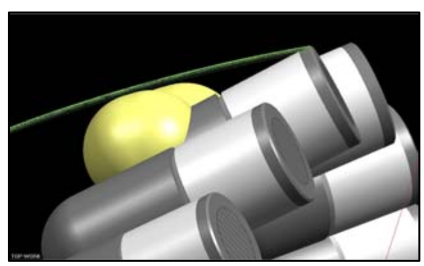


Figure 4 and Figure 5 – Impact Arrestors to Dampen Axial Vibration
Impreg disks within arrestors are visible in Figure 4.

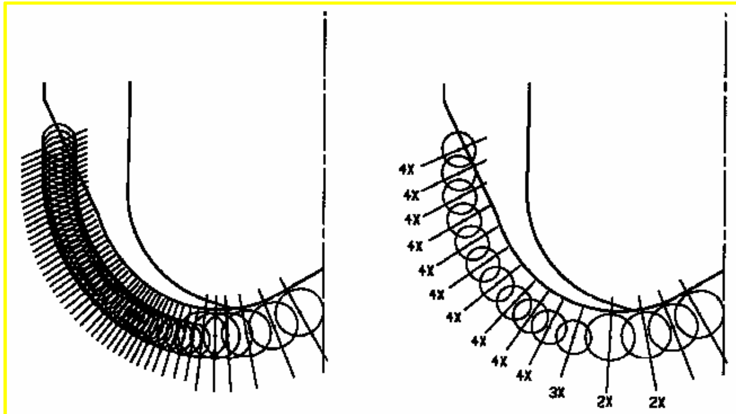


Figure 6 – Single Set Cutting Structure of a PDC Bit on the Left
and Track Set Cutting Structure on the Right

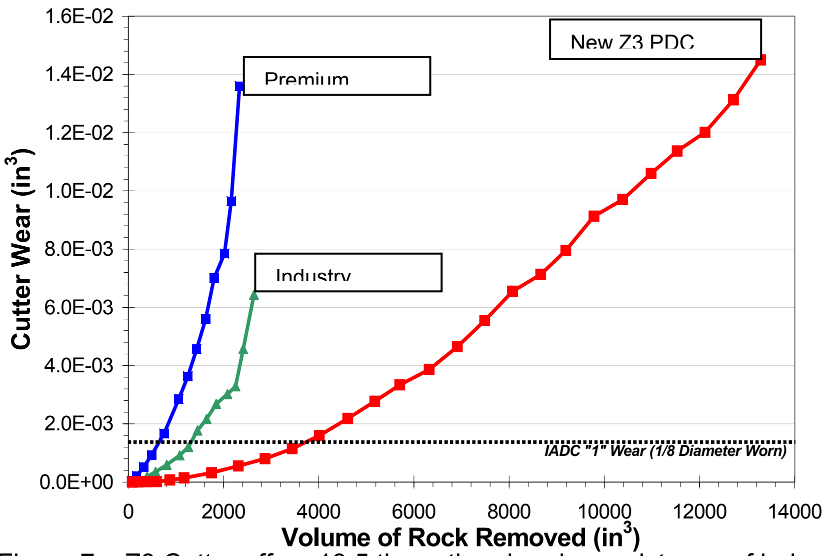


Figure 7 – Z3 Cutter offers 13.5 times the abrasion resistance of industry standard cutters.

Figure 8 – Latest design – FM2745R

Figure 9 – Dull FM2745R after Drilling Entire 7 7/8-in. Interval of 8,860 feet in 126.5 hours at an average of 70 ft/hr.