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Improving PDC Bit Design: A Case Study for 17.5 mm PDC Cutters

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Abstract

Advancements in rig, drill string, and BHA components in recent years have dramatically increased the amount of energy being delivered to the drill bit in terms of hydraulic energy, torque, weight, and RPM. PDC bit designs, consequently, grew more aggressive as operators seek to maximize rate of penetration. At the same time, directional requirements for most intervals have become more crucial and complex as multi-well and multi-bench pad drilling plans have evolved. A key design element governing a PDC drill bit rate of penetration potential is cutter exposure, or the height of the cutter above the blade top. At a high rate of penetration, once the cutter is fully engaged, the blade itself becomes a bearing surface resulting in achieving higher depth of cut difficult. The issue has grown to the level where the currently standard 16 mm cutting element PDC bits are rapidly approaching the cutter exposure maximums that still ensure adequate pocket depth for brazing and durability. While 19 mm cutting elements are available, case history shows underperformance due to design limits as well as excessive reacting torque inhibiting directional performance. Recent development of a 17.5mm cutter addresses these issues by enabling greater design flexibility with regards to increased exposure and depth of cut without incurring excessive levels of reactive torque. Design options also have greater flexibility in cutter placement and diamond volume on a given profile with the 17.5 mm relative to a 19mm cutter. The result of designing and properly deploying this novel cutter size has resulted not only in reductions to cutter damage but also improved drilling footage and rate of penetration.

Introduction

The first commercial success of PDC drill bits is credited to their deployment in the North Sea in the mid 1970’s (Scott 2015). Since the 2000’s, PDC drill bits have grown to the dominate the United States land drilling market. From vertical sections to tight hole applications, the demands of PDC bit technology has rapidly increased, especially with the ever-increasing reach of lateral sections in horizontal drilling. As PDC technology established itself across the many diverse drilling acreages across the United States, certain ‘key’ technologies, or design selections, grew to be standard in particular applications. Besides the obvious OD of the drill bit being directly tied to the hole size being drilling, design options such as number of blades, nozzle count, PDC cutter count, PDC orientations, bit body material, and over a dozen other design criteria can all be modified by drill bit designers to attempt to deliver the best possible tool for the drilling challenge at hand. While some of the options exhibit a wide range of design options, i.e. blade counts ranging from four to eight or the sheer number of different PDC cutter design iterations available, the diameter of PDC cutters available is incredibly restrictive. For the majority of US land drilling applications, PDC cutters are only available in 11,13,16, and 19mm diameters; and 11mm and 19mm cutters are niche even still (Devers et al 2022).

The limitations posed by being forced between one of two cutter diameters subsequently forces design engineers to design bits around negative trade-offs of the selected option. As an application transitions into one that could be viewed being more benign, it becomes more favorable to make design decisions that favor drilling speed over longevity or durability. The major issue with this that after 16mm cutters, the next jump is to 19mm cutters, which are typically viewed as too much of a risk to the onset of torsion for any potential returns in drilling speed. Additionally, the potential demand increase for this technology gap is only likely to increase, as the EIA reported the majority of annular production is generated through newly developed wells. As a result of this circumstance, the development of a new PDC cutter was initiated with the caveat being the diameter needed to be larger than the existing 16mm options.

Designing the 17.5mm Cutter

To best identify the applicability of a new cutter diameter, an application of deployment opportunity had to be determined. Review of existing designs and drilling applications led to the selection of a 12.25” OD drill bit made of steel with 6 blades designed for deployment in transitional rock in the Permian. Additionally, it is known that this application is subject to a particular amount of direction work, which would be cause for concern in deployment of 19mm cutters. The profile, and average PDC wear trend, of the selected design can be seen in **Figure 1**. From this analysis, it was determined that throughout the cone and face sections of the bit, total diamond area removed (DAR) ranged from roughly 5 to 15% of the total cutter area of each cutter. The wear was observed to be the highest in both the area of cutter one, the first cutter along the profile, and in cutters just after the nose along the shoulder of the bit.

Having selected a profile, an effort was undertaken to further optimize the design in an effort to increase the potential ROP of the design. To do this, a more comprehensive investigation into the nature of the wear incurred by the cutters, an example of which is shown in **Figures 2 & 3**. The results of this investigation determined that there was evidence a larger diameter cutter would be appropriate in this application. This is generally seen by the nature of the diamond loss on the cutters. A generalized diagram of cutter engagement is shown in **Figure 4**, but there are known restriction on just how much of the cutter can practically engage formation; an example of this is shown in **Figure 5**. In this case, in order to engage more of the diamond of the cutter, a larger PDC cutter would have to be used. However, engineering application experience determined the traditional 19mm cutter was unable to be deployed in this application due to the necessity for slide control while drilling.

The solution to this problem was to build a never before deployed cutter diameter. While it may be possible to design a bit to mitigate the known issues of a 19mm cutter for the target application, the perception of the cutter alone would give reason to not make a design desirable to test due to potential risk. Consider the jump from 13mm to 16mm PDC cutters. The total area increase is roughly 68mm^2, or roughly a 50% area increase. However, there isn't necessarily a 50% increase in the available engagement area. Design restrictions along the profile of the bit might reduce that. Jumping from 16mm to 19mm would result in approximately the same percentage change, but a larger absolute change. This, in turn, would again limit options in design. To mitigate this, the selected diameter of 17.5mm was selected. This diameter increase is more in line with the absolute area increase gained when moving from a 13mm cutting element to a 16mm cutting element, only increasing the total available area by 39.5mm^2. Once this new diameter was determined, a new cutter was developed based on application history for deployment in a redesign of the investigated case study bit.

Redesign Deployment Results

In this case study, to date, the 17.5mm cutter has been deployed as a dominate cutter in 27 like or exact case uses. **Figure 6** below showcases the original design and average cutter wear state alongside the new design profile and wear state. The profile shapes are nearly identical, and this is by design. The entire process was focused on optimization, and the primary optimization factor was the cutter OD. From wear state analysis alone, improvements were noted immediately in the cutter one location in the cone of the bit, and average wear by cutter improved along the entire cone and into the nose and shoulder of the bit. These are strong results as it indicates we are onboarding less relative area loss per cutter, and does not speak to absolute area loss. If the DAR percentages were the same, or nearly the same, there would cause for concern as there would inherently be a larger amount of diamond loss per cutter. But , results indicate results that would suggest less total diamond was being lost, as the wear states on some of the cutters are near-zero.

Maintenance of the diamond table on cutters is an indicator of performance, but the goal of the redesign was to enhance ROP. **Figure 7** plots the average ROP and footage of the 27-case study runs against all incumbent run data record. The new design saw an absolute average ROP increase of 14.6 ft/hr, or an 8.6% improvement from the incumbent design. Additionally, the new design saw an increase of average footage of 8%, increasing an average 283 ft per run. Even further analysis of optimization verification as conducted by investigating the differential pressure and weight on bit of a targeted run. Seen in **Figure 8**, an idea of bit aggressivity and efficiency can be determined. In theory, any bit could achieve a high ROP if enough weight is applied to it. In practice, however, the bit would fail mechanically before any requisite WOB could be achieved. With this in mind, the WOB can be viewed as the energy put into the system, and the differential pressure the energy out. The more differential pressure (energy out) you get for a given WOB (energy in) indicates that the drill bit is more efficient. Therefore, a steep slope indicates a more efficient cutting structure and a more aggressive design. The graph is split into 5 different hole depths to visualize the relationship clearly in different formations (these do not line perfectly with formation tops). This is further evidence that the cutting structure is efficient in the case study application.

Conclusions

- The utilization and demand of PDC drill bits in the industry was established.
- The lack of available options of PDC diameters was established.
- The need for additional cutter diameters was established through identification of emerging industry demand, and an appropriate diameter established.
- A PDC bit designed to bring 17.5mm cutters to market was manufactured and subsequently deployed in field.
- Wear state analysis of the new design show a decrease in DAR percentage and suggested an overall absolute decrease in DAR.
- Utilization of the new design over incumbent 16mm designs yielded an average ROP increase of 8% and footage increase of 8.6%
- Review of EDR data from case study runs also indicated an increase in drilling efficiency in addition to traditional metrics of improvement.

Acknowledgments

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Nomenclature

Define symbols used in the text here unless they are explained in the body of the text. Use units where appropriate.

BHA = Bottomhole assembly
PDC = Polycrystalline Diamond Cutters
RPM = Rotations per Minute
EDR = Electronic Drilling Record
DAR = Diamond Area Removed

References

1. Bruton, G., Crockett Malcolm Taylor, R., DenBoer Jeff Lund Provo, D., Craig Fleming Robert Ford Gary Garcia Allen White, U., Teel, M., von Flatern, R., & Wilshusen, E. (2014). *PDC Bit Technology for the 21st Century*.
2. Devers, Cameron, Dyer, Warren, and Dustin Lyles. "Automated Forensic PDC Dull Analysis Enables Digital Feedback Loop." Paper presented at the SPE Annual Technical Conference and Exhibition, Houston, Texas, USA, October 2022. doi: https://doi.org/10.2118/210044-MS
3. U.S. Energy Information Administration. Drilling Productivity Report. (2023).
4. Scott, Dan. "A Bit of History: Overcoming Early Setbacks, PDC Bits Now Drill 90%-plus of Worldwide Footage." *Drilling Contractor*, 9 July 2015,

Figures

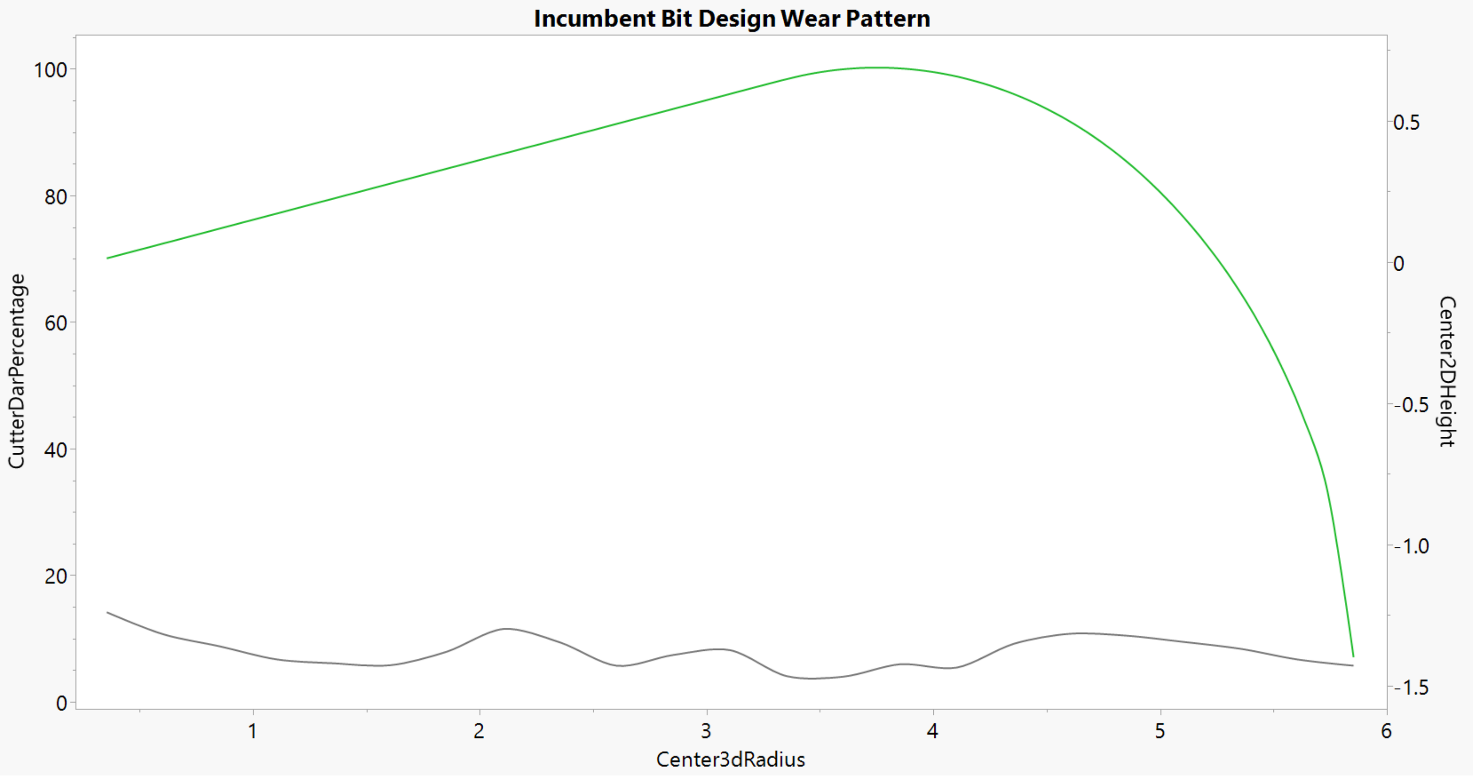

Figure 1 –Profile and wear state trend for the incumbent 6 blade steel body PDC bit with 16mm cutters

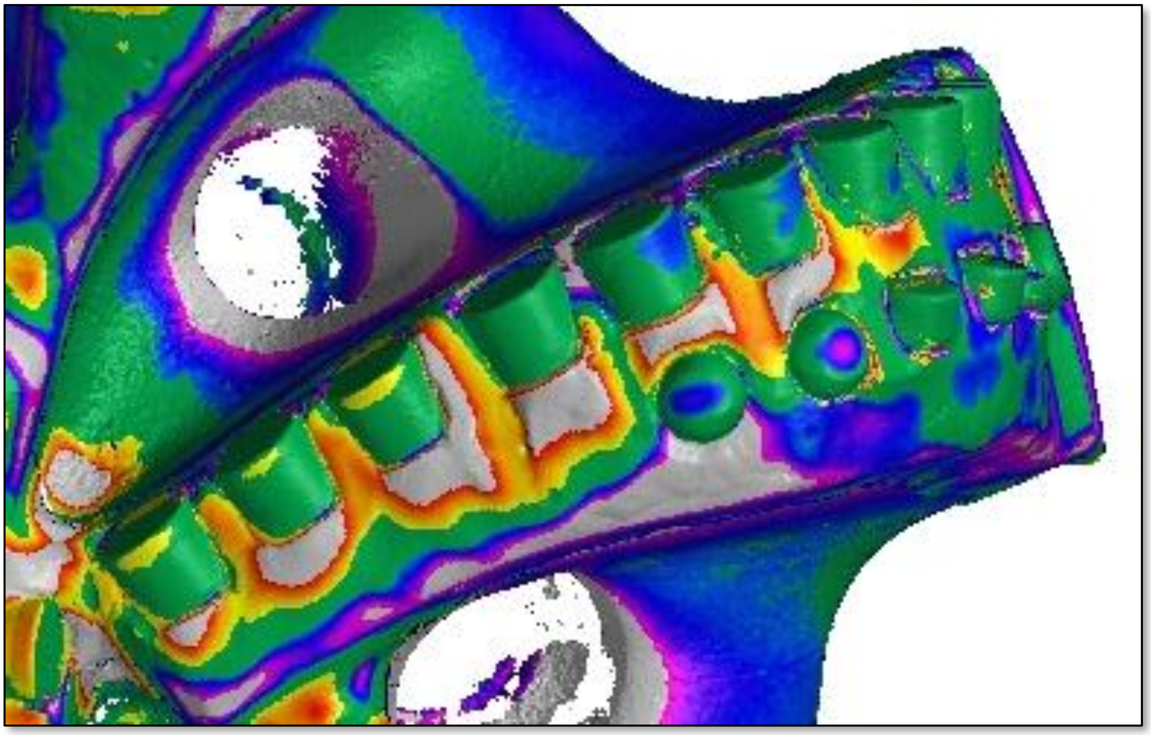

Figure 2 – Cutter wear analysis with bit body investigation

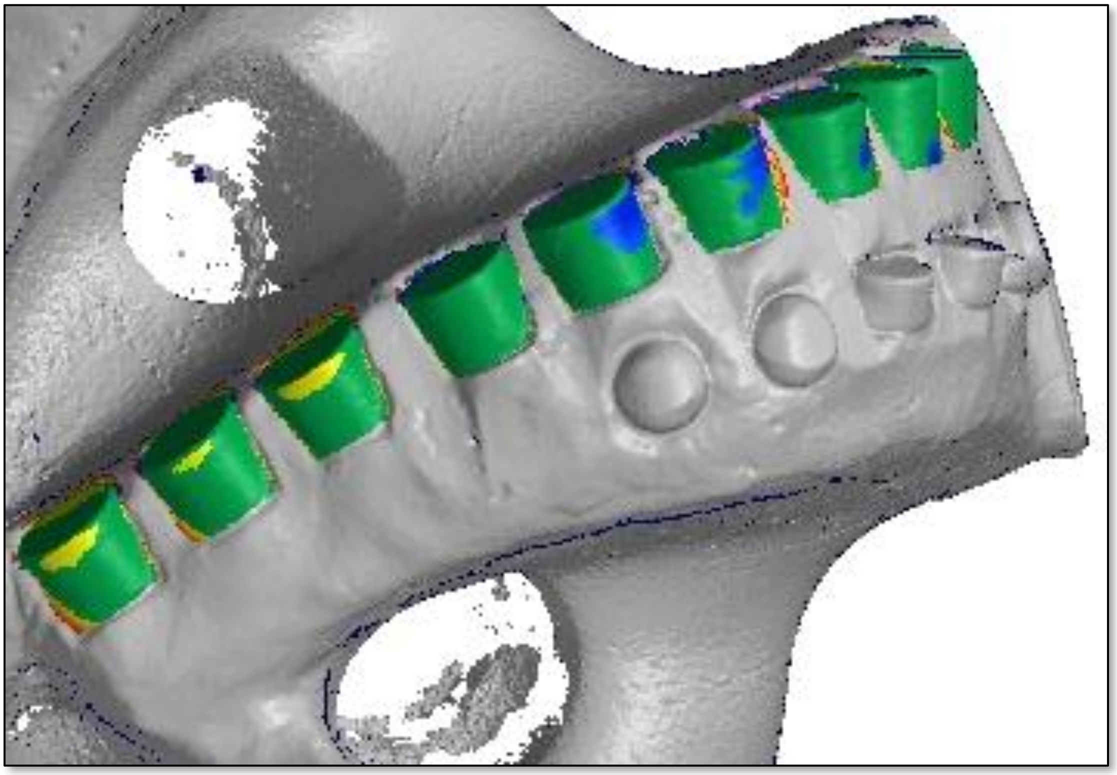

Figure 3 – Cutter wear isolating just cutter damage

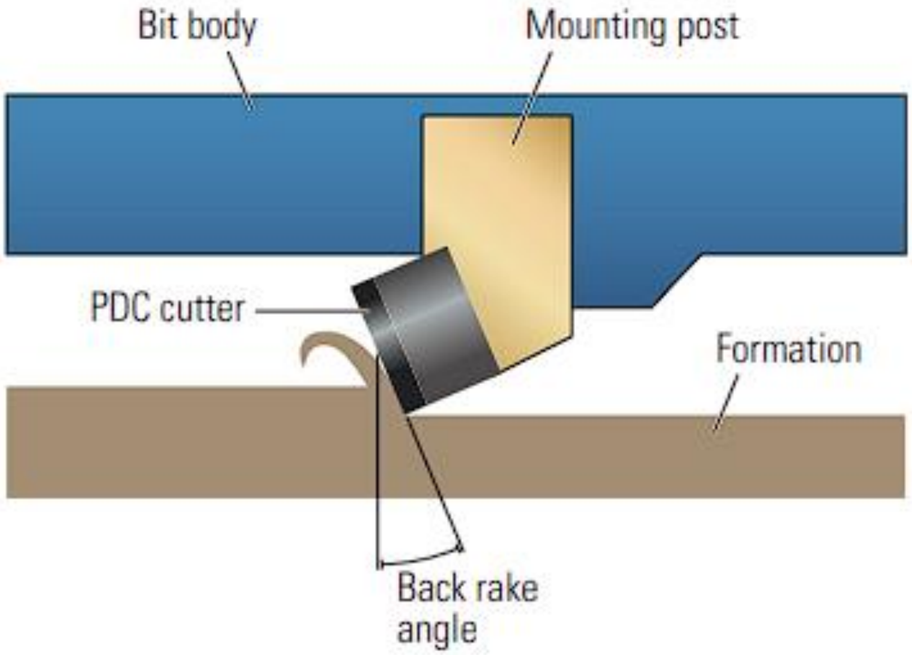

Figure 4– Diagram showing the PDC bit design parameter back rake, which also showcases PDC cutter formation engagement (Bruton et al. 2014)

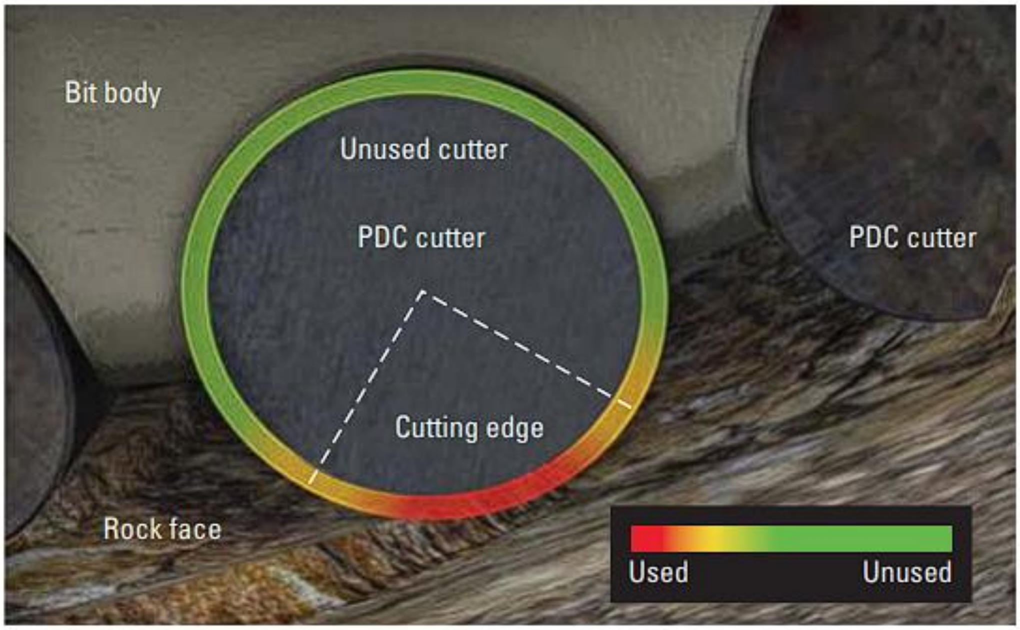

Figure 5 – Depiction of limited engagement area of a PDC cutter (Bruton et al. 2014)

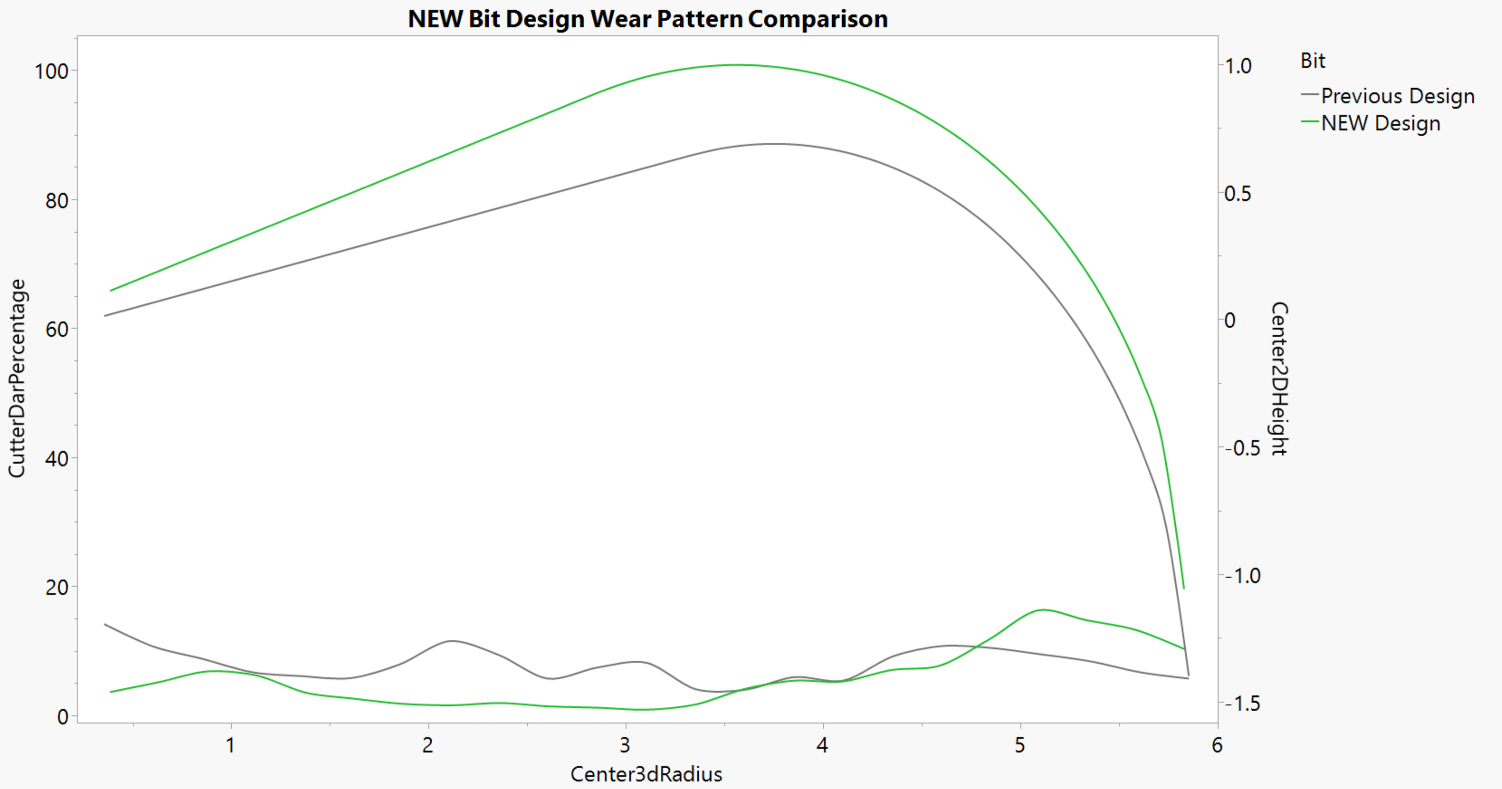

Figure 6 –Profiles and wear state trends for the incumbent 6 blade steel body PDC bit with 16mm cutters and new like design for 17.5mm cutters

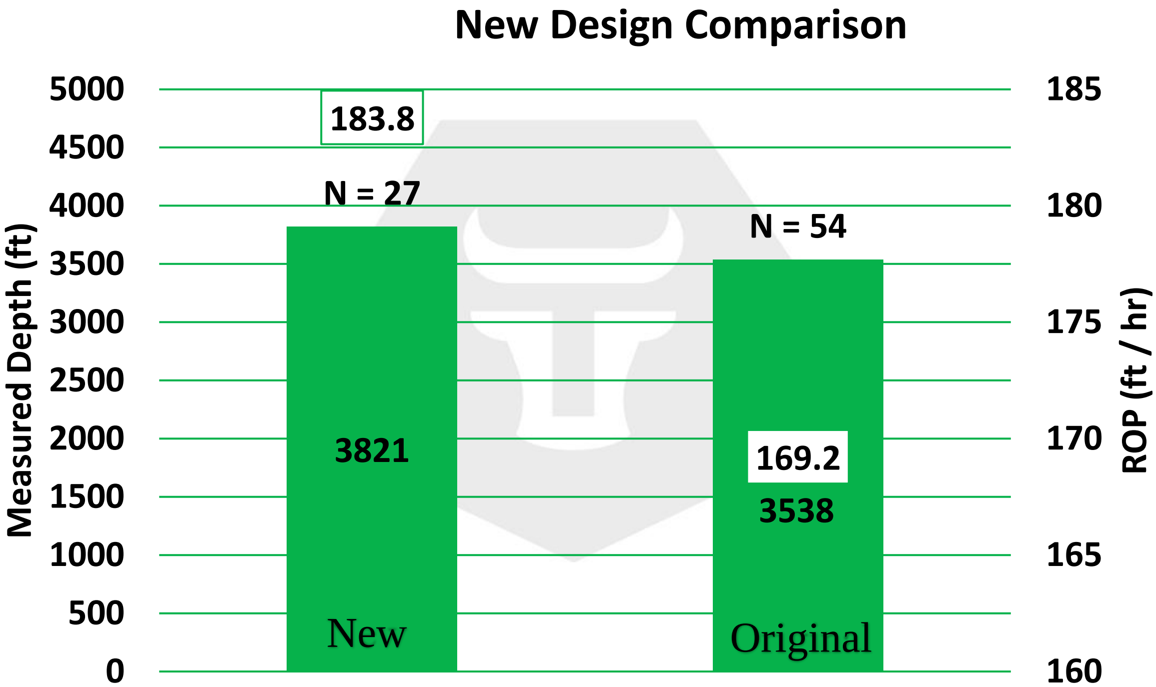

Figure 7 –Performance comparison between the original and new PDC bit design, noting the 8% ROP improvement and 8.6% footage improvement in the new design

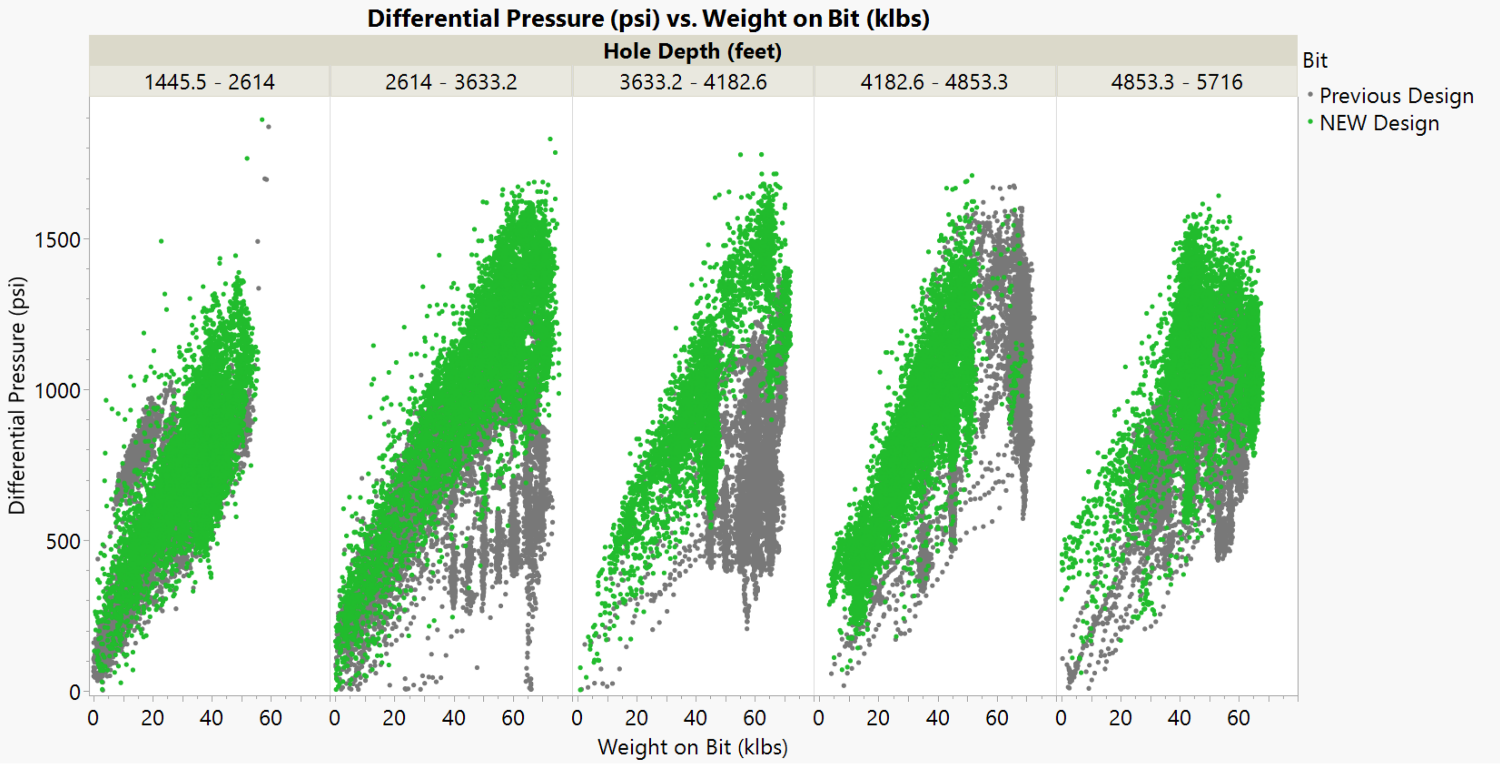

Figure 8 –EDR based efficiency analysis of the new design focusing on weight on bit and differential pressure.