



## Milling the Window and Drilling the Lateral in One Trip: Case Histories and Developments

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### Abstract

Polycrystalline diamond compact (PDC) insert cutting structures are now being used on casing sidetracking mills. These mills are able to effectively mill a casing window and drill formation. The mills can consist of single or multiple milling profiles and have been used with directional drilling assemblies.

The use of these mills can result in substantial cost savings, milling reliability and sidetracking efficiency. The number of runs and assemblies necessary to complete the well can be reduced and additional objectives can be accomplished while on-bottom. Utilization of this new PDC based technology adds economic viability to remedial wells, new wells and total field applications.

This paper presents the results of the use of this new technology used in several wellbores around the world. Specific field case histories from the Sultanate of Oman, South America and the United States of America are presented to show the varied applications of this technology.

### Introduction

The financial side of petroleum production challenges operators to deliver greater quantities at lower costs. Oil service companies have responded to this challenge by optimizing present techniques and developing new technology. Historically, polycrystalline diamond compact inserts have been used for the drilling of formation. PDC bits have proven effective in many of today's drilling environments. Through innovative material technology, these PDC cutting elements now offer a cost-effective approach to creating multiple wellbores from the same mother bore.

Through sharing of corporate technology, the development of the PDC casing cutting element was achieved. These cylindrically shaped elements are now capable of milling steel and drilling formation. This new cutting structure was incorporated into the design and concepts of the One-Trip Sidetracking System (**Fig. 1**).<sup>1</sup>

The PDC cutters are strategically located on the cutting profile of the sidetracking Lead Mill (**Fig. 2**). The precise location of the cutters is controlled by multiple axis machining processes. Through this process, exact

duplication and consistency of Lead Mill manufacture is accomplished. With these qualified process controls in place, the critical design criteria for the Lead Mill is no longer controlled by the skill of the crushed tungsten carbide applicator or welder. Although the "state of the art" crushed carbide mills used to perform casing sidetracks today achieve their objectives (**Fig. 3**), consistency of construction is near impossible. A more consistently manufactured product leads to consistent field performance. With the advent of the Drill-Ahead Mill, cutting a window and drilling formation in one trip can become a predictably consistent process.

### Drill-Ahead System

The objective of this system is to use a directional drilling assembly to first mill a casing sidetrack window and then to proceed with drilling the lateral all in the same trip. The basis of this system is to further the objectives established for the One-Trip Sidetracking System. Those objectives were to accomplish in a single trip the steps necessary to produce a full size casing window and a full size rathole in a minimum amount of time. The focus of the Drill-Ahead System would accomplish these steps employing a PDC dressed Lead Mill.<sup>2</sup>

**Case History No. 1.** The first application of a directional milling assembly was in the Sultanate of Oman in August 1999. The objective of the sidetrack was to mill the casing window and continue to drill and steer an extended lateral to avoid an existing gas well. The well was located in the Saih Rawl Field and the sidetrack was performed in the Natih formation. It was the seventh leg of a seven leg multilateral well.

The whipstock assembly was run in the hole using the One-Trip Sidetracking System Mill. This mill was only used to convey the whipstock assembly and not used for the initial cutout or any window milling. A PDC Mill was run on a directional motor with a 1.4° bent housing and MWD tool. The PDC Mill completed the casing window and drilled 312 feet of formation. Penetration rates of 49-65 ft/hr. were achieved and this was a better ROP than most tricone and PDC bits used in the field. The run was terminated due to MWD failure and the mill was 3/16-in.

under gauge upon inspection.

**Case History No. 2.** The next development with the PDC Drill-Ahead System was a multilateral application in the Saih Rawl Field in February 2000. This was the first use of the Mud Motor Lock-Up Tool in the sidetracking assembly. This device is located above the mud motor and prevents output shaft rotation during MWD orientation and hydraulic setting of the anchor.

The sidetrack took place in Leg No. 3 of a multiple leg well program. The system was run in the hole, oriented and set in 7-in., 34.2 lb./ft., K-55 casing. Window milling commenced and 23.6 inches of casing was cut before the Mud Motor Lock-Up Tool malfunctioned. This assembly was pulled out of the well and the window was completed with a One-Trip Sidetrack Mill.

Since this job, the Mud Motor Lock-Up Tool has been redesigned and is awaiting further field trials.<sup>3</sup>

#### **PDC Bimill Applications in Colombia, South America**

The PDC Bimill was first used in northeastern Colombia, South America in the Cupiaqua and Cusiana oil and gas fields starting in March 1999. The mill proved effective in drilling the Llanos Basin's Guadalupe and Mirador formations that were opposite the casing window exits.

The typical sidetracking application involved two trips. The One-Trip Sidetracking Mill was used to mill to centerpoint on the whipstock. The PDC Bimill then replaced it on the second run to complete the milling of the window and drill the desired length of rathole or lateral. This technique was first devised as a way to deal with formations that cause rapid wear on standard crushed tungsten carbide dressed mills.

**Formations.** The Guadalupe and Mirador sandstone formations are known for difficult drilling conditions due to their composition and high compressive strengths. The formations have low porosity, but good permeability and that allows for high production rates. The composition of both sandstones is quartz-cemented quartzarenites.<sup>4</sup>

The Guadalupe formation has compressive strengths that range from 26,000 to 30,000 psi. The Mirador's unconfined compressive strengths are greater than that of the Guadalupe in the Cupiaqua field. Also, the unconfined compressive strengths are greater in the Cupiaqua field formation than those in the Cusiana field. The formations are very abrasive for drilling bits. Bit runs with TCI cutters average less than 100 feet.

**Case History Study.** A review was conducted of 10 jobs that employed the sidetracking technique utilizing the PDC Bimill. All the sidetracks were performed in 7-in., 32-lb/ft. casing with grades of L-80 and P-110. Whipstock assembly setting depths ranged from within 14,800 ft. to 17,900 ft. TD. The average sidetrack milling

and drilling time was 4.5 hours with an average rathole length of 5.3 ft. The One-Trip Sidetracking Mill, that was dressed with both preformed and crushed tungsten carbide inserts, milled an average of 4.8 ft. at an average ROP of 1.9 ft/hr. The PDC Bimill milled and drilled an average of 7.9 ft. with an ROP of 5.8 ft/hr. The average wear on the two milling profiles on the PDC Bimill was less than 1/8-in. on the Lead Mill and 5/32-in. on the Follow Mill.

#### **Drill-Ahead System in the San Juan Basin**

The first applications of the Drill-Ahead System without a steerable mud motor were successfully accomplished in the San Juan Basin along the Colorado and New Mexico border in coalbed methane gas wells. The operators needed a cost-effective well plan that could achieve a sidetrack through casing with an extended lateral that would terminate at a specific geologic marker without using a directionally steered BHA. The Drill-Ahead System with the PDC Bimill was able to do this task in one trip.

A review of four case histories describes how the casing windows and laterals were achieved with better than expected ROP's and with lateral lengths ranging from 176 to 565 feet.

The operators use of this Drill-Ahead System enabled them to save 2½ days of operations, reduce trips and associated costs, work safer, and return the wells to production 2 days sooner over previous techniques.

**Case History No. 1.** The first job was completed in November 1999 in La Plata County, Colorado. The job was performed in one run with the casing window exit and 560-ft. lateral being milled and drilled with the PDC Bimill in a total of 12 hours.

The whipstock assembly was hydraulically set at 319 ft. TD in 7-in., 23 lb./ft., J-55 casing. The BHA consisted of the whipstock assembly, PDC Bimill, crossover, heavy weight drill pipe and drill pipe. The hook-up between the whip and mill is similar to what is used with the One-Trip Sidetrack Mill. However, with the PDC Bimill, the hook-up fastens at the bottom of the mill instead of from the side (**Fig. 4**).

After the mill was sheared from the whip, the window was milled in 3 hours at an ROP of 2.67 ft/hr. The PDC Bimill drilled the lateral through siltstone, shale, coal and sandstone formations at an ROP of 62.2 ft/hr. with a low solids water based drilling fluid. The Lead Mill was 1/8-in. under gauge and sustained several chipped PDC cutters which was considered normal (**Fig.5**).

**Case History No. 2.** The Drill-Ahead System technique of using the PDC Bimill with a non-directional BHA was again applied in 5½-in. casing. The whipstock assembly was oriented by gyro and hydraulically anchored at 2713 ft. TD in a vertical well. The 4¾-in. OD mill cut the window exit in the 15.5 lb./ft., K-55 casing with 8.4 ppg

drilling fluid in 3.2 hours. The lateral was then drilled after switching from drilling fluid to air/mist. The run was halted due to a drop in ROP when chert stringers were encountered. The PDC Bimill was replaced with a drilling assembly. The window and 176-ft. lateral were completed in one run in 18.75 hours.

**Case History No. 3.** The Drill-Ahead System was employed to mill a window in 7-in., 23 lb./ft., N-80 casing and drill a lateral. The PDC Bimill was able to mill the 8-ft. window and 565-ft. lateral in 16.3 hours less the connection make-up time. The window was milled in 2.3 hours. The mill was run with 1-2,000 lb. weight for milling and at 95 RPM. The mud system was converted to air/mist prior to drilling the lateral. The mill drilled the sandstone and shale formations with 2-8,000 lb. weight and 65-95 RPM. The run averaged an ROP of 35 ft/hr. The Lead Mill of the PDC Bimill was 1/16-in. under gauge at the end of the run (**Fig.6**).

**Case History No. 4.** The well was located in Rio Arriba County, New Mexico. The PDC Bimill milled the window and drilled the lateral in one run in 15.2 hours. The mill completed the 8-ft. window exit in 3.50 hours with a ROP of 2.29 ft/hr. The 437-ft. lateral was drilled in 11.7 hours with a ROP of 37.48 ft/hr.

The whipstock assembly was hydraulically anchored at 3780 ft. MD in 7-in., 23 lb./ft., J-55 casing. The PDC Bimill was sheared from the whipstock assembly when the new connector hook-up was sheared with a tensile overpull of 30,000 lb. The window was milled with water and a working RPM and weight of 100 and 1-2,000 lb. respectively. The lateral was drilled with air/mist with a working RPM of 90-100 and a weight range of 1-12,000 lb.

#### **Open Hole Sidetrack with PDC Bimill**

The PDC Bimill was instrumental in the success of a screw-in type open hole sidetrack around a fish at depth of 22,448 ft. MD in Point Coupee Parish, Louisiana. The job was accomplished in three runs. On the first run, a special whipstock-BHA was attached to the fish. The PDC Bimill was then used to drill a 46-ft. lateral beyond the whip face and past the fish on the second run. A third BHA was run to wash and ream the sidetrack and lateral and to drill new hole.

The BHA was as depicted in (**Fig. 7**), but without the need for the Hydraulic Swivel and MWD. A specific orientation of the whip face was not needed. The assembly was tripped into the hole to the top of the fish. The crossover sub was threaded into the top connection of the fish and torqued with 12,000 ft.-lb. The shear-off sub was sheared from the whip with a tensile load of 30,000 lb.

The PDC Bimill was used to drill down the whip face and a 46-ft. lateral through sandstone and shale

formations. The full 54 feet (window and lateral) required 23 hours of drilling at an ROP of 2.3-ft/hr. with an RPM of 60 and WOB of 2-10,000 lb. The drilling fluid was 14.5 ppg oil-based mud. The torque and drag of the assembly passing along the whip face and through the full-gauge lateral were checked prior to tripping out of the hole. The Lead Mill was in gauge with the Follow Mill being 1/8-in. under gauge.

A final check run was made with a BHA consisting of a bit and several watermelon mills before picking up a directional assembly. The assembly washed and reamed down the whip face and through the lateral to TD. Eighteen feet of new hole was then drilled.

#### **West Texas PDC Bimill Applications**

The first applications of the PDC Bimill in the Permian Basin of West Texas were as a backup to the standard One-Trip Sidetrack Mill. Preliminary use of the PDC Bimill was to finish the sidetrack after progress with the One-Trip Sidetrack Mill had been halted due to hard formations. The mills with PDC-based cutting structure proved to be more effective in handling the chert stringers than the mills with welding-applied preformed and crushed tungsten carbide cutting structures.

**Case History No. 1.** The PDC Bimill proved successful in completing the window exit and rathole on a sidetrack in West Texas in Upton County. The One-Trip Sidetrack Mill was replaced after its milling rate declined after passing centerpoint on the whip face and encountering a hard formation.

The whipstock assembly was set at 10,250 ft. MD in 7-in., 26 lb./ft., L-80 casing after being directionally oriented by gyro. The mill cut the first portion of the window (4.68-ft.) at a ROP of 1.22 ft/hr with milling parameters of 85 RPM and 4-6,000 lb. WOB. The Lead and Follow Mill profiles were 1/16-in. and 1/8-in. out of gauge respectively on the One-Trip Sidetrack Mill. The mill showed signs of heavy wear with the crushed tungsten carbide dressing worn smooth.

The PDC Bimill was used on the second run to cut the remaining 3.07-ft. of casing at a rate of 2.52 ft/hr. and 4-ft. of formation at a rate of 3.15 ft/hr. The parameters for cutting both the casing and formation were 110 RPM and 2-4,000 lb. WOB. The Lead Mill and Follow mill profiles were 1/8-in. and 1/16-in. under gauge.

The total 11.75-ft. of sidetrack was completed in 6.32 hours.

**Case History No. 2.** As in the previous case history, the PDC Bimill was used on the second run to complete the 7-in. casing window exit and necessary gauge rathole. Again, the hard formation had impeded the One-Trip Sidetracking Mill from completing the window.

The whipstock assembly was oriented by gyro and

the anchor hydraulically set at 11,700 ft. MD. Although the mill had stopped making progress, the milling profiles were still in gauge. The PDC Bimill finished the last 2 feet of the window with an ROP of 0.80 ft/hr. and drilled the 4 feet of rathole in 30% chert formation with a ROP of 0.75 ft/hr. The cutting structure on the PDC Bimill was in gauge after 6.5 hours of milling and drilling.

**Case History No. 3.** The sidetrack was to be completed in one run with the standard One-Trip Sidetracking System. However, the unforeseen presence of 30% chert opposite the window made it necessary to finish the job with the PDC Mill.

The casing window was initiated at a depth of 11,834-ft. MD in 7-in., 29 lb./ft., P-110 casing. The first mill was able to mill 5-ft. of casing at an ROP of 0.5 ft/hr. The second mill failed to make any progress against the casing and formation. The PDC Bimill was then picked up on the third run to mill the last 3-ft. of the window and drill 3-ft. of rathole in the hard formation. The mill was in gauge at the end of the run (**Fig. 8**).

**Case History No. 4.** This sidetrack was accomplished in one run by employing the PDC Bimill with the One-Trip Sidetracking System. The PDC Bimill was used in place of the standard One-Trip Mill because of its proven ability to drill the rathole in hard chert and limestone formations after milling the lower portion of the casing window.

The well was a vertical well located in Midland County, Texas. The whipstock assembly was attached to the PDC Bimill with the new hook-up (**Fig. 9**). The whipstock anchor was first oriented by gyro and then hydraulically set at a depth of 11,663-ft. MD in 7-in., 26-lb/ft. casing. The PDC Bimill was sheared from the new connector hook-up to the whipstock assembly with 30,000 lb. overpull. The window exit and 3 feet of chert-limestone formation were cut in 13 hours at an ROP of 0.85 ft/hr. The mill's RPM for both casing and formation was 100. The WOB was 1-5,000 lb. in the casing and 5-10,000 lb. in the formation. The Lead Mill was 3/16-in. under gauge and the Follow Mill was 1/8-in. under gauge.

## Developments

Since the first laboratory tests and field trials were conducted, improvements and innovations have been made. The mode of attaching the drill string and PDC Mill to the whipstock assembly was improved to create a sidetracking BHA that can be more reliably deployed through wells with greater tortuosity. The concept of using cylindrical cutting elements, along with the consistency of product manufacturing and improved performance, was applied to the design of the One-Trip Sidetracking Mill with the incorporation of enhanced tungsten carbide cutting structures. Finally, research and development of improved PDC cutters, mill designs and

the Mud Motor Lock-up Tool continues in an effort to produce sidetracking systems that meet the ever increasing operator demands and objectives.

**New Connector for Hook-up.** A new connector was designed for attaching the whipstock assembly to the PDC Bimill. It was first run in the San Juan Basin of New Mexico and then in the Permian Basin of West Texas. During the course of these jobs, the stronger hook-up was proven-out. It was able to support the hanging weight of the whipstock assembly, keep the mill aligned with the whipstock and combat the induced torque on the BHA while being tripped into the wellbore and oriented. The design also allows for a better fit between the mill and whip tip. The connector is easily milled away during the milling of the first foot of the casing window exit (**Fig. 10**).

**Enhanced Tungsten Carbide Mill.** The Enhanced Tungsten Carbide (ETC) Mill was derived from the successes seen with the PDC Mill. The ETC Mill is an advancement of the One-trip Sidetracking Mill. It incorporates the design principles of the One-Trip Sidetracking Mill with the cutting structure, manufacturing and performance criteria of the PDC Mill.

The profile of the Lead Mill of the ETC Mill is that of the Lead Mill on the One-Trip Sidetrack Mill. It has the same milling tasks during the course of the sidetrack. The cutting structure is composed of enhanced tungsten carbide cylinders specifically placed in the integral blades of the Lead Mill. The enhanced carbide is a milling grade of carbide designed for medium hard formations (**Fig. 11**). The Follow Mill's cutting structure remains composed of preformed and crushed tungsten carbide dressing as found on the One-Trip Sidetrack Mill.

**Case History No. 1.** The first application of the Enhanced Tungsten Carbide Mill was performed in West Texas in Terrell County in December 2000. A 6-1/8 in. OD ETC Bimill was used with the One-Trip Sidetrack System to achieve the sidetrack in one run in 7-in., 26 lb./ft. casing with 5-ft. of rathole being drilled through limestone in 8 hours.

The mill had a milling ROP of 1.25 ft/hr. and a drilling ROP of 3.3 ft/hr. The mill averaged 100 RPM and a working weight range of 1-6,000 lb.

The Lead Mill sustained chipped ETC cutters and was 1/8-in. under gauge and the Follow Mill profile was in gauge (**Fig. 12 and 13**). The integral blade cutting structure was reconditioned and redressed with new cutters. Performance of the new mill was considered very good by the operator.

**Case History No. 2.** A second application of the Enhanced Tungsten Carbide Mill was carried out in the San Juan Basin of New Mexico in January 2001. The

sidetrack was completed in one run in 2.25 hours using the ETC Trimill with the One-Trip Sidetracking System. The whipstock assembly was set in 7-in., 23 lb./ft., J-55 casing at a depth of 371-ft. MD.

The mill cut an 8-ft. casing window and drilled a 10-ft. rathole through a hard sandstone and shale interval. The working RPM was 120 for the whole sidetrack with the WOB in the casing being 1-2,000 lb. and 4-6,000 in the formation. The mill achieved a milling ROP of 5.33 ft/hr. and a drilling ROP of 13.33 ft/hr. The mill consisted of three milling profiles: Lead, Follow and Dress. The Lead Mill (Fig. 14) and Follow Mill were both 1/8-in. under gauge. The Dress Mill was still full gauge after the run.

**New PDC for Cutting Structure.** The manufacturer of the PDC cutters has continued to do extensive development testing since the first cutter material tests were conducted over three years ago. High impact resistance is still the prime characteristic for identifying the best PDC with the right composition for milling various grades of casing and formation hardnesses. Advancements have been made in materials and processes to achieve better cutter stability, less edge-chipping and less interface damage.

Presently, a PDC Bimill for 7-in. casing is awaiting an opportunity to be run in the field to test a new grade of PDC cutter. The sizes of the PDC Mills that have been run range from 3½ to 7-5/8 in. OD. Currently, an 8½ in. OD PDC Bimill is being run to mill a casing window and drill a short lateral in Norway.

## Conclusions

The following conclusions were derived from these case histories and developments of the PDC Bimill, ETC Mill and Drill-Ahead System.

- The PDC Bimill is able to mill casing and drill high compressive strength formations.
- Application of the non-directional Drill-Ahead System allowed the operator to reduce costs and time, work safer and return the well to production more quickly.
- The use of the PDC Bimill can be instrumental to the success of open hole sidetracking efforts in hard formations.
- Successful applications of the PDC Bimill have gained its acceptance as an integral part of the One-Trip Sidetracking System.
- The newly designed connector was shown to withstand the dynamic stresses on the BHA during sidetracking operations.

The Enhanced Tungsten Carbide Mill's cylindrical cutting structures and mode of manufacturing proved to be an innovative alternative to conventional tungsten carbide dressing.

## Looking Ahead

Future multilateral sidetracking opportunities are being sought for the steerable Drill-Ahead System with the Mud Motor Lock-up Tool. Perfecting this sidetracking technique will enable the operator to achieve a directionally steered sidetrack and extended lateral.

The company will be pursuing greater worldwide implementation of the PDC Mill in its various forms with the Drill-Ahead and One-Trip Sidetracking Systems as customer interest and experience grows.

Also, additional field trials will be done to see how well the ETC Mill handles different casings and formations and sidetracking scenarios. Positive results will verify that the concept of using cylindrical cutting elements is a viable alternative to the traditional mill dressings. This will establish that ETC cutting structures are enhancements to the One-Trip Sidetracking System.

## Acknowledgements

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## Nomenclature

*PDC = polycrystalline diamond compacts*

*BHA = bottom hole assembly*

*ROP = rate of penetration*

*RPM = revolutions per minute*

*TD = total depth*

*WOB = weight on bit*

*OD = outside diameter*

*PPG = pound per gallon*

*MD = measured depth*

*ETC = enhanced tungsten carbide*

*MWD = measurement-while-drilling*

*PSI = pounds per square inch*

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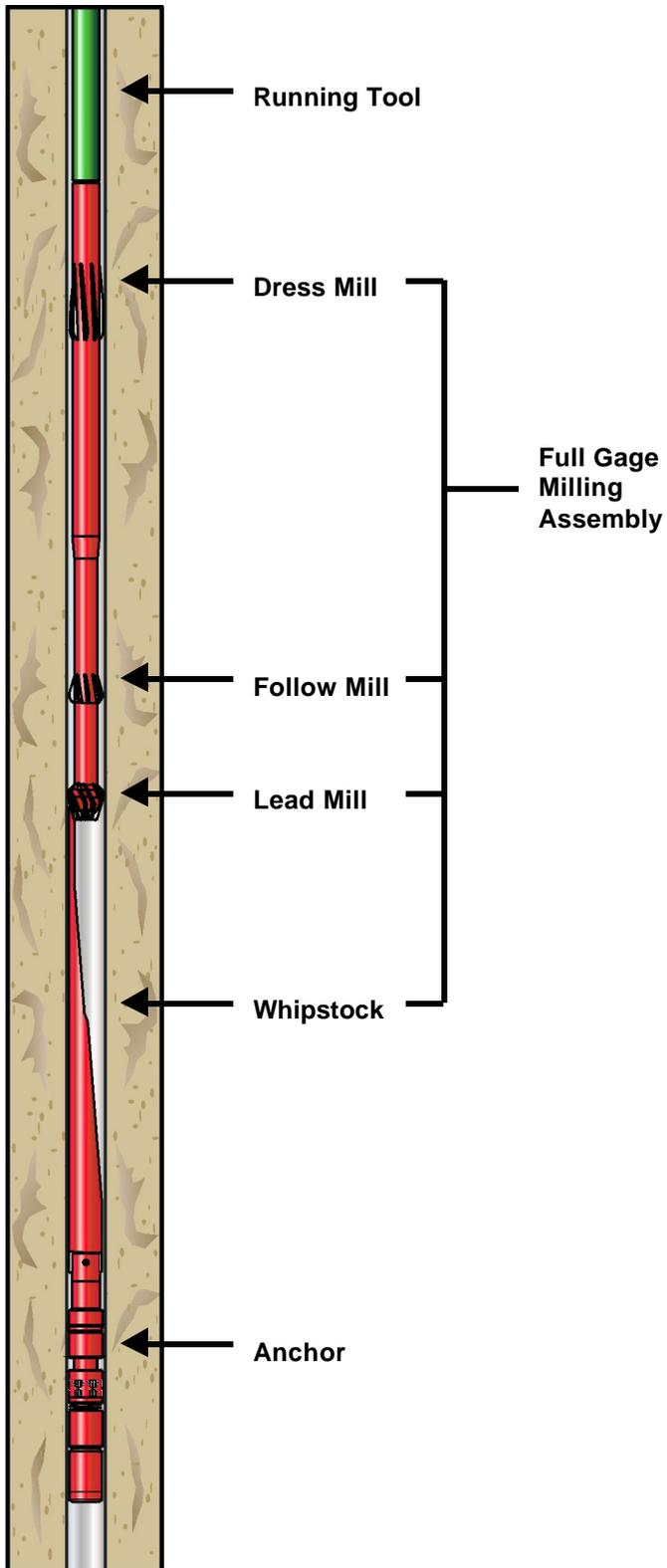


Figure 1 - One-Trip Sidetracking System. (Modified version of Fig. 9 of Ref. 1).



Figure 2 - Standard PDC Bimill for 7-in. casing with only PDC cutting structure on Lead Mill profile and preformed and crushed tungsten carbide dressing on the Follow Mill profile.



Figure 3 - State of the art dressing of preformed and crushed tungsten carbide on Lead Mill of One-Trip Sidetracking System mill.



Figure 5 - PDC Lead Mill only 1/8 in. under gauge after milling a window through 7-in. casing and drilling 560 ft. lateral in 12 hours and in one run.



Figure 4 - First method for attaching PDC Bimill to hydraulic whipstock assembly.



Figure 6 - PDC Lead Mill is 1/16-in. under gauge after cutting a window through 7-in. N-80 casing and drilling 565-ft. lateral in 16.3 hours and in one run.

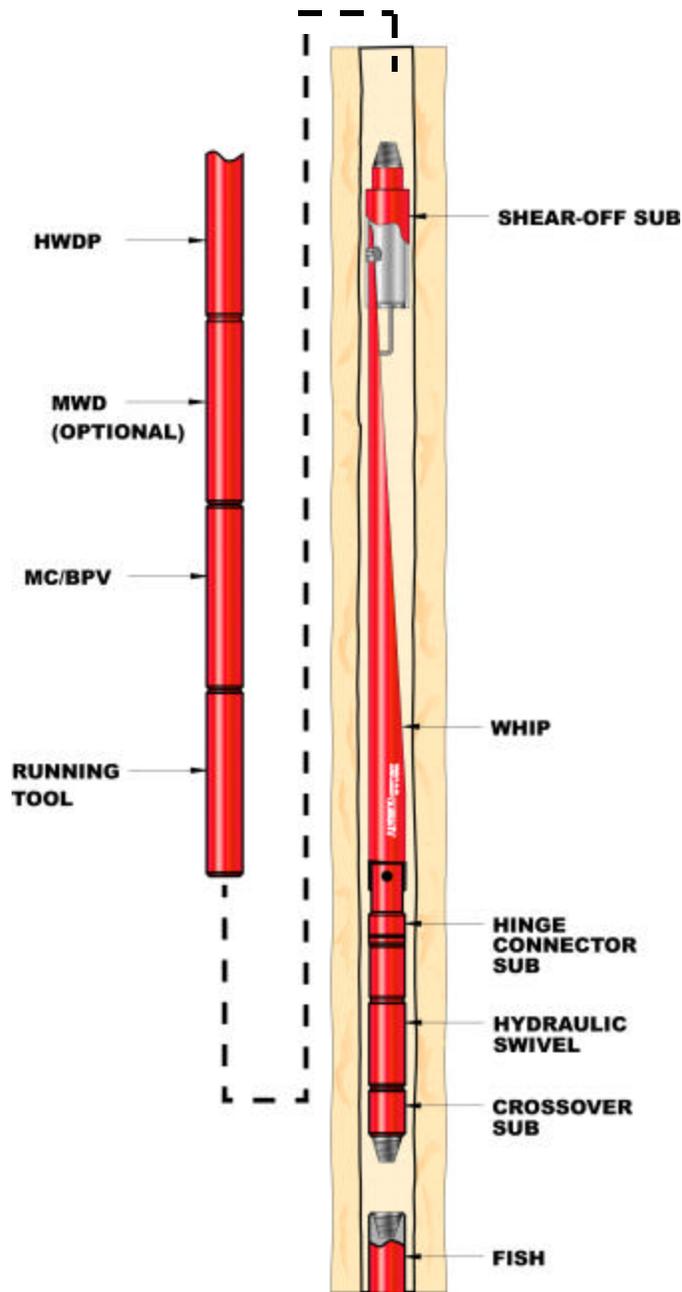


Figure 7 - Screw-in type open hole sidetracking system.

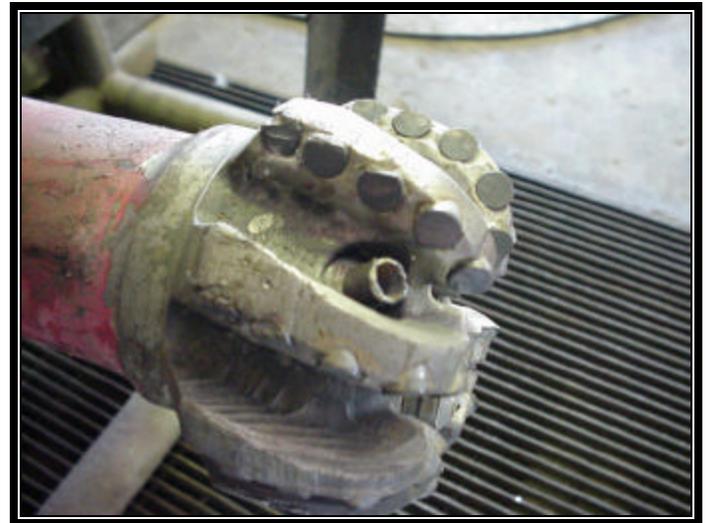


Figure 8 - PDC Lead Mill still in gauge after milling 3-ft. of casing and 3-ft. of formation with 30% chert.

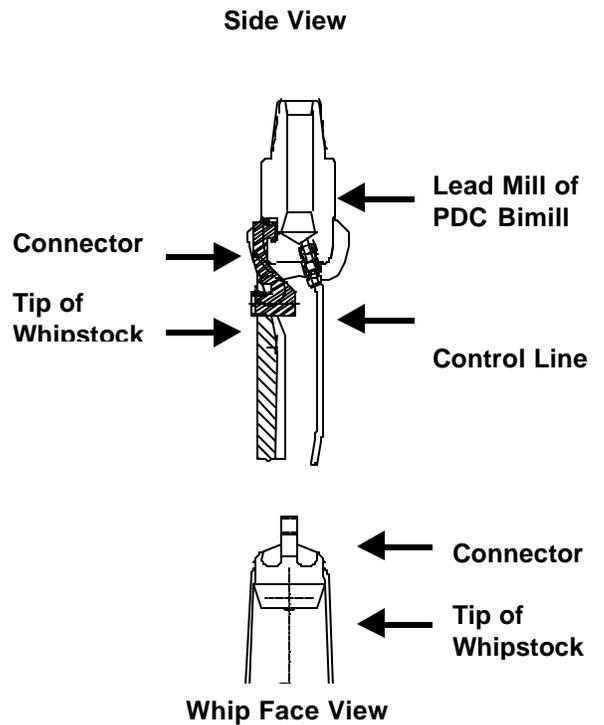


Figure 9 - New connector between whipstock and PDC Bimill for great strength and torque capacity. (Drawing modified from Fig. 9 of Ref. 3.)



Figure 10 - New connector between whipstock and PDC Bimill used on West Texas and San Juan Basin.



Figure 12 - ETC Lead Mill after 8-hour sidetrack.



Figure 11 - Lead Mill dressed with ETC cutters. Hole through the mill is used for attaching it to whipstock.



Figure 13 - Follow Mill still in gauge after 8 hours.



Figure 14 - Lead Mill with ETC cutting structures after milling 8-ft. of casing window and drilling 10-ft. of sandstone-shale formation in 2.25 hrs.