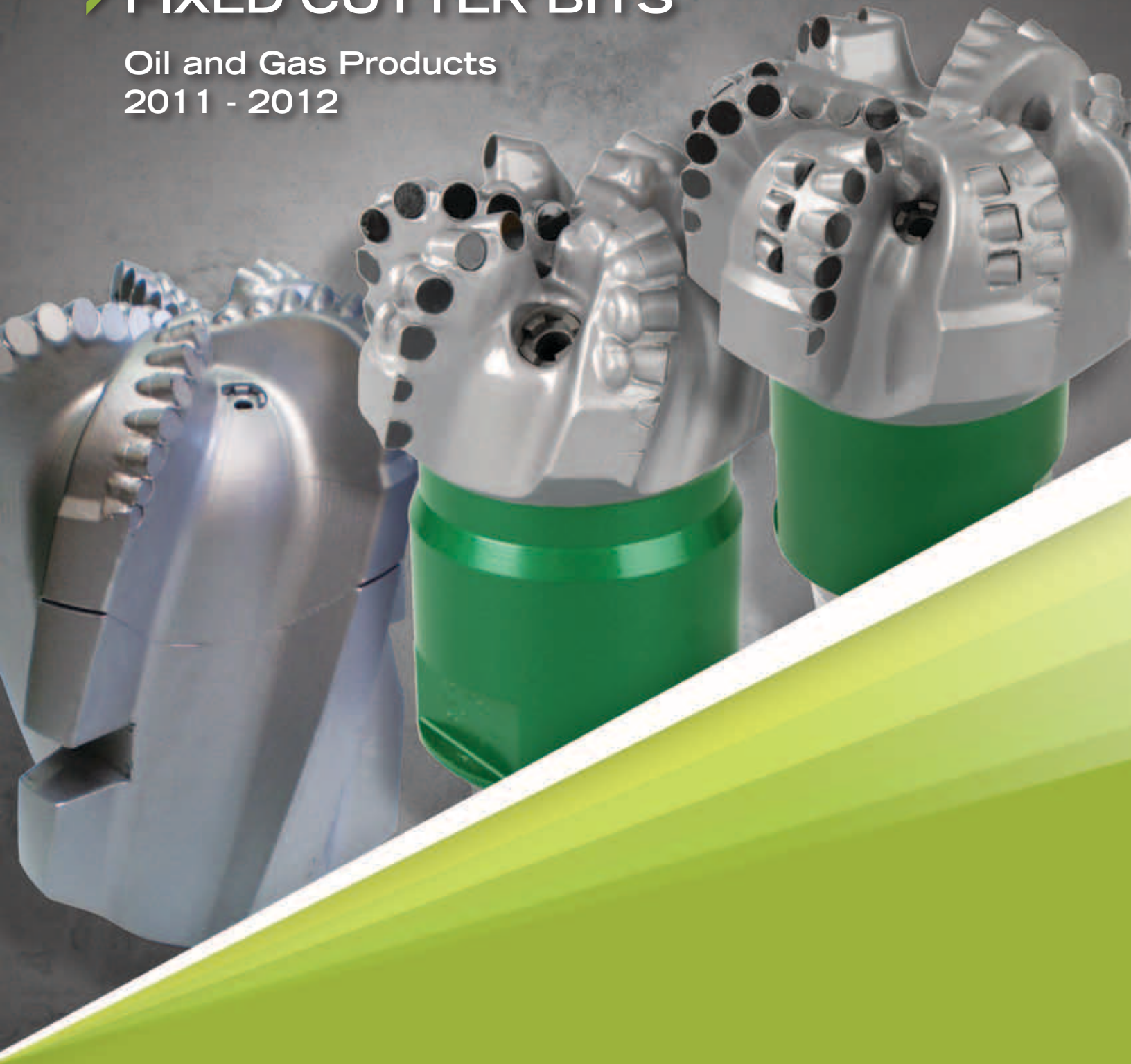
FIXED CUTTER BITS

Oil and Gas Products
2011 - 2012



VAREL INTERNATIONAL

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About Varel International

"We will deliver ever-increasing value to our customers and other stakeholders by exceeding industry standards for performance, service and innovation."

Founded in 1947, Varel International is the world's largest independent supplier in the global oil & gas drill bit market. Varel offers a comprehensive product line of roller cone and fixed cutter (PDC) drill bits that have evolved and improved through patented drill bit technologies and emerging drilling technologies.

Varel aligns its engineering and manufacturing capabilities to provide customers with high-quality products that deliver reliability and optimum performance.

- High-quality manufacturing
- Product and process innovation
- Delivering integrity in all of our relationships
- Responsibility towards health, safety, and the environment
- Creating customers for life

Scan our updated catalog for our latest products, features and premium options. Then contact the Varel sales office near you to discuss innovative and cost-effective solutions for your next drilling project.

Varel Fixed Cutter Bit Technology

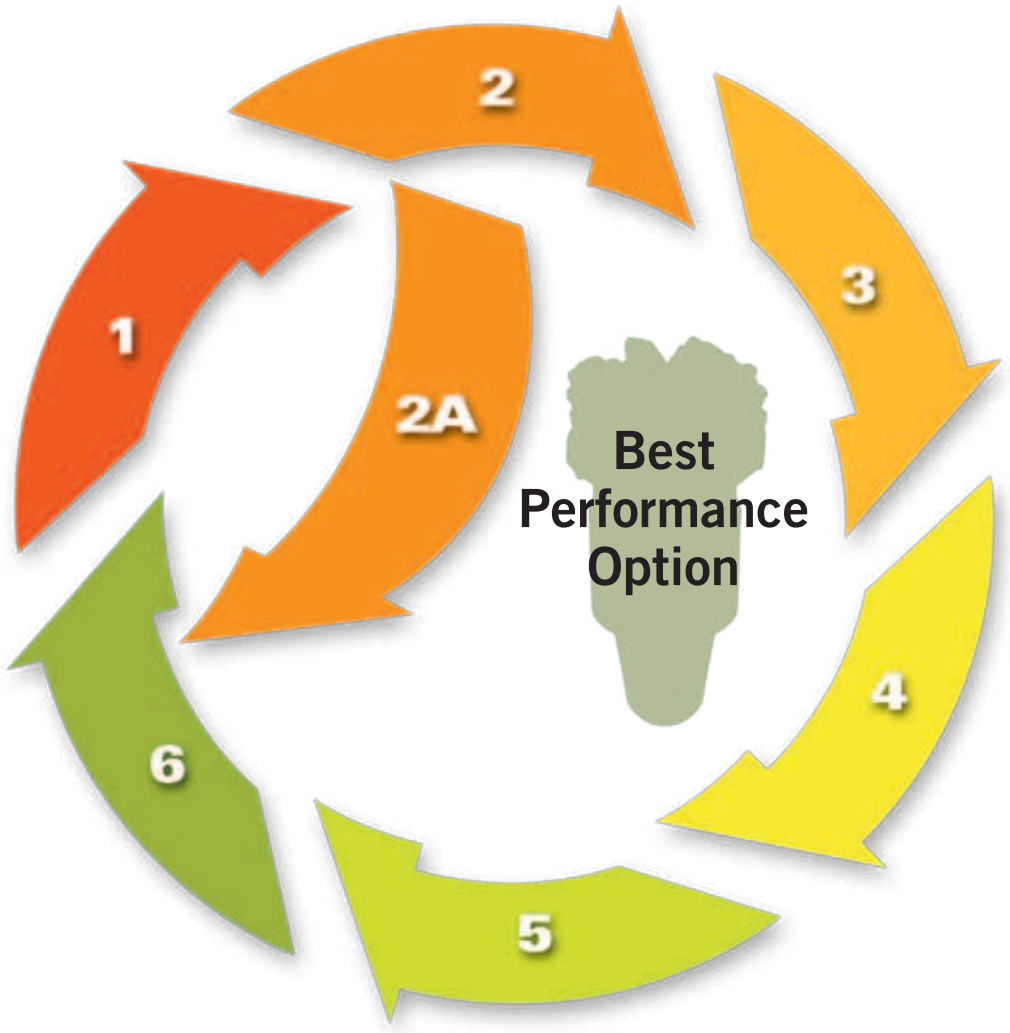
Innovation Driven Technology

Delivering the Cutting Edge

Varel continues to push the limits of fixed cutter technology through its aggressive approach to technological innovation.

Delivering the best product, getting the job done – and doing it well – is the core of the company. State-of-the-art technology platforms allow us to deliver the cutting edge products and performance you need for all of your drilling challenges.

Varel's suite of software tools is designed to seamlessly move from the definition of the drilling challenge to the right drill bit solution. These software modules have been carefully developed to move complex data from one stage to the next without the need for keyed data re-entry or translation. All critical data is carried forward step to step.



Step 1: GeoScience™ Initial Analysis

Performance benchmarking and bit record review proceeds to analysis of rock properties from customer log data. When coupled with the well plan, this analysis quantifies the drilling challenge.

Step 2: SPOT™ Design Software

SPOT cutting structure design is employed to create a cutting structure that will meet the drilling challenge. The SPOT mathematical model is used to perform a drilling and wear simulation to verify it corresponds with the GeoScience findings.

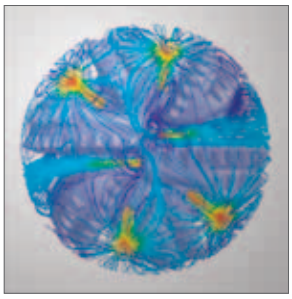
Step 2A: Existing Bit Design

If appropriate, an existing bit design is recommended to meet the requirements of the GeoScience analysis.

Step 3: Pro-Engineer CAD

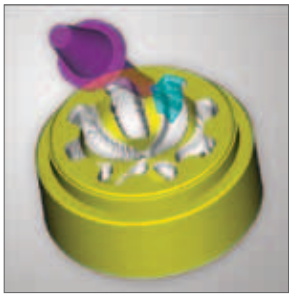
Pro-Engineer CAD design system, custom developed for drill bit body design, is used to design a complete bit 3D model incorporating the SPOT cutting structure.

Step 4: Computational Fluid Dynamics



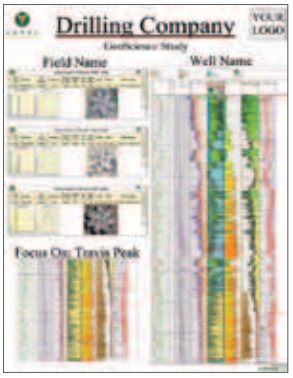
CFD analysis is employed to optimize the fluid flow characteristics of the CAD model. The model aids in the analysis of the cooling and cleaning characteristics of the 3D model.

Step 5: Pro-Engineer CAM



Completed bit design is then programmed for the complete CNC manufacturing process to produce the bit.

Step 6: Bit Run and GeoScience Post Run Analysis



GeoScience is once again used to analyze the bit's performance versus the initial plan and prognosis. If needed, the initial GeoScience analysis is recalibrated prior to the start of a new iteration of bit design.

Varel Fixed Cutter Bit Technology

Custom PDC Cutter Development and Selection

Taking custom cutting structures to the next level

Varel International has expanded its commitment to technological excellence with the addition of an application-specific PDC cutter analysis process. Varel's test regimen standardizes PDC testing and allows Varel to develop and select the optimum cutter for the application. The ability to qualify PDC cutters from multiple suppliers results in:

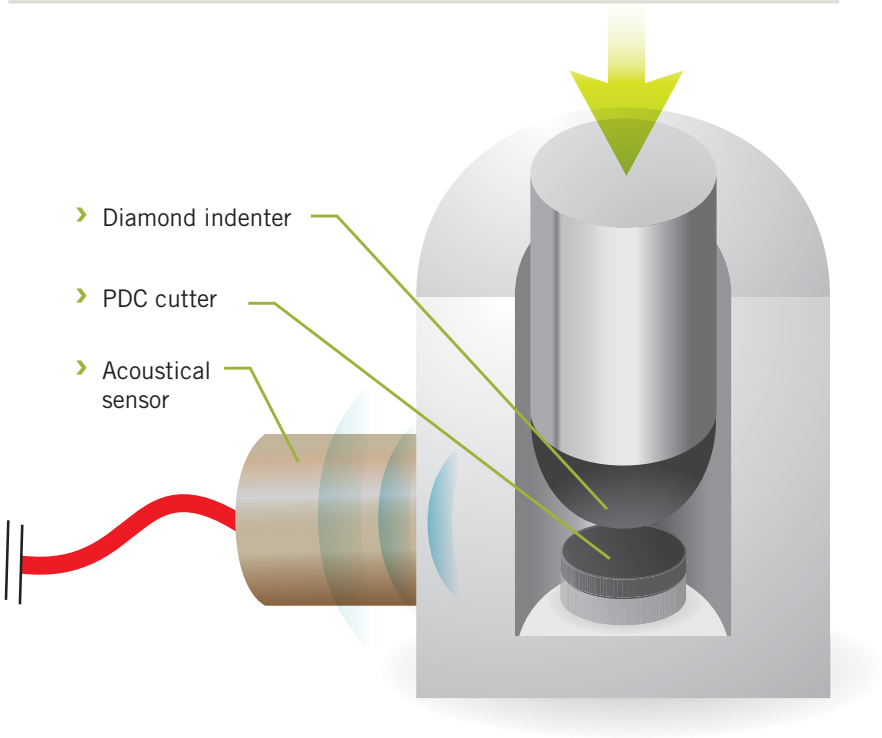
- Enhanced cutter selection to suit the application
- Access to technology from a variety of suppliers
- Qualification and validation of cutter performance

The company's highly qualified team of scientists works with premier cutter suppliers, universities and field engineers to guide the development and selection of cutters for Varel's line of premium PDC drill bits.

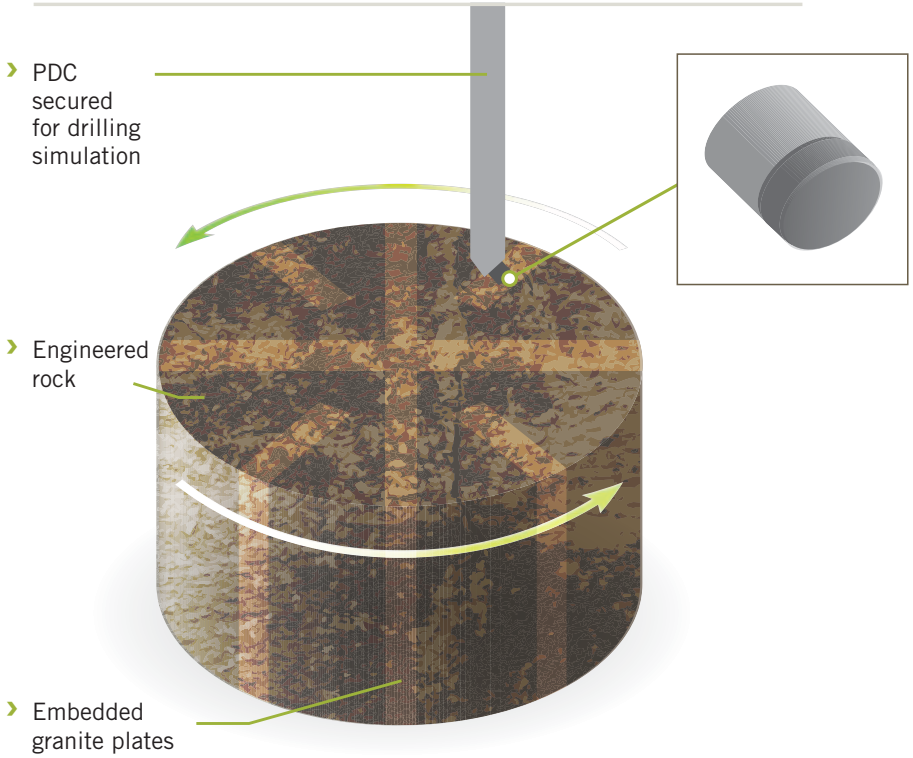
Testing Methodologies for Drilling Applications

Today's drilling challenges the cutter's toughness and abrasion resistance. High energy drilling environments often require thermostability and toughness. Varel's dedicated cutter team has recently developed and deployed new and innovative tools that enhance and improve the development and selection of the best cutter technology for the application.

ACOUSTICAL EMISSIONS TOUGHNESS TEST



BIMODAL ABRASIVE ROCK TEST



Cutter Toughness

Cutter toughness is the ability to withstand the effects of drilling dynamics. Toughness is related to the strength of the diamond-to-diamond bonding created during the High Pressure High Temperature (HPHT) sintering of the PDC cutter. Historically, test methods in the industry have been qualitative and have fallen short of providing effective data for field cutter selection.

To better measure cutter toughness, Varel has developed its patent-pending **Acoustical Emissions Toughness Test (AETT)**. **AETT** quantitatively assesses the strength of the diamond-to-diamond bonding. With this test, a load is applied to the cutters and increased at a constant rate while recording the acoustic emissions from microcracking in the diamond table. Measuring the energy released during microcracking yields a concrete assessment of the PDC toughness.

Abrasion Resistance

Abrasion resistance is the cutter's ability to stay sharp as it drills. A second patent-pending test, the **Bimodal Abrasive Rock Test (BART)**, is a laboratory abrasion resistance test that employs two drastically different rock samples. The two rock samples create a load/unload cycle to simulate interbedded formations and formation transitions. By recreating this environment, **BART** provides a more suitable measurement of abrasion resistance correlating to field performance.

Navigator Bits

Specifically designed for directional drilling

Varel International's Navigator line of PDC drill bits have been designed for maximum performance in directional drilling. Increasingly complex well paths, tighter targets, greater attention to wellbore quality and longer extended reaches, require drill bits specially engineered for optimal operation of a steering tool's mechanism and geometry, as well as for use with certain rock formations.

Under development since 2004, Navigator series bits have been used on every type of steering system from all major manufacturers to accommodate the entire spectrum of directional drilling requirements.

Developed for customization and optimization

Navigator series technology was developed through extensive laboratory testing. Test results were incorporated into the algorithmic engines of Varel's proprietary suite of advanced software analytical tools: GeoScience™ and SPOT™, Varel's cutting structure design and drilling simulation system.

Using these tools, Navigator bit designs can be evaluated, customized and optimized to produce the best possible bit for the operator's specific directional profile and lithology column.

› Updrill Feature

When drilling a directional well, such negative outcomes like hole wall sloughing, keyseating, or severe dog legs can occur. Varel's updrill feature allows hole wall cleaning as you ream the wellbore, helping eliminate such problems.

› O-Ring Studs

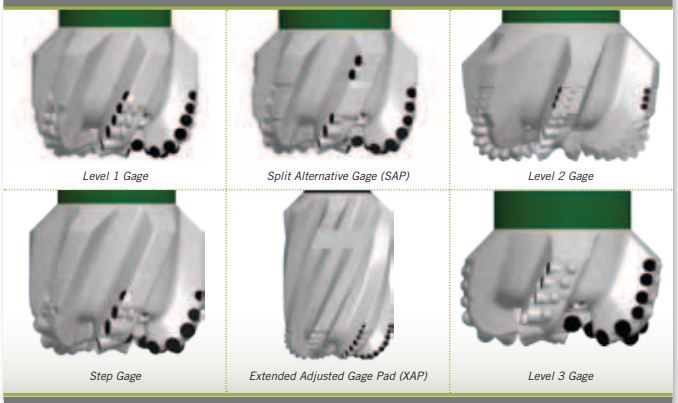
Additional matrix material in the shape of an o-ring is placed directly behind specific cutters. This additional material helps manage the torque generated by modern steerable systems while maintaining orientation for increased ROP and reduced sliding time.

Active gage designs are required in some push-the-bit systems to enhance lateral deviation for more efficient drilling.

› Specifying the correct gage for the system

The gage section of a PDC bit must be matched to the cutting structure to achieve the desired steering response. Varel has performed laboratory and field tests on over 25 different gage configurations to validate the Navigator series gage design matrix. It is this matrix that is used to match a specific Navigator bit to the rock formation, well design and steering system.

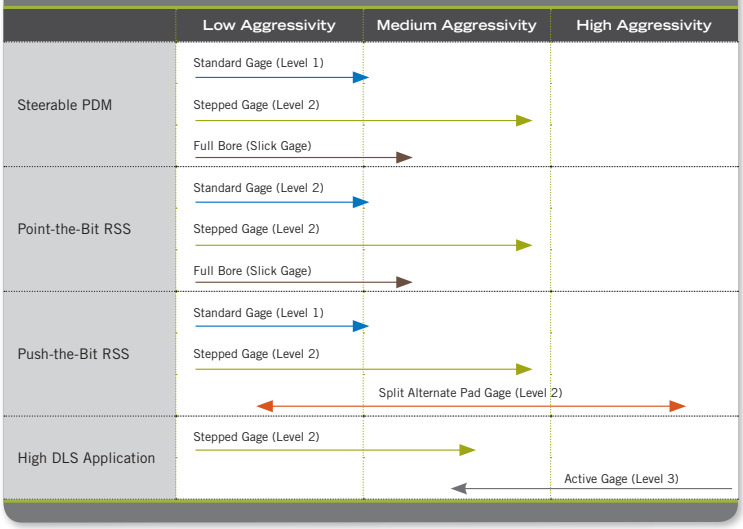
› Navigator Gage Systems



› Putting it all together

Navigator bits are analyzed for force balance, axial and lateral displacement. Each Navigator bit has a steerability factor calculated into it. The bit is simulated in conjunction with the expected side forces, which is generated by the specific steering tool being used.

› Fixed Cutter PDC Bit Gage Application Matrix



› Adapted to work with a variety of drilling systems

As the largest independent supplier of PDC drill bits worldwide, Varel is in a unique position to adapt drill bits to steering tools from a broad spectrum of suppliers.

› Navigator Series Bits Run on the Following Systems

Manufacturer	System Model	System Type
Baker Hughes	Auto Trak ®	RSS - Push/Point
	Verti Trak ®	RSS - Push
Schlumberger	PowerDrive X5*	RSS - Push
	PowerDrive Xceed*	RSS - Point
	PowerV*	RSS - Push
Halliburton	Geo-Pilot ®	RSS - Point
	SlickBore ®	PDM - Directional
Smith Pathfinder	Pathmaker ® 3D	RSS - Point
Weatherford Precision	Revolution ®	RSS - Point

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**PowerDrive X5, PowerDrive Xceed and PowerV are marks of Schlumberger.*

Tough-Drill PDC Bits

Tough-Drill PDC Bit

SPOT™ Models Bit Behavior

Varel's Tough-Drill™ PDC bits are designed for tough drilling applications. Due to their improved stabilization characteristics, these bits address the ROP and durability challenges experienced when drilling hard and/or abrasive formations.

Continuous discussions with our growing customer base, coupled with extensive engineering and research focus, contributed to the development of Tough-Drill bits. These bits continue to improve drilling performance in hard and abrasive formations with compressive strengths in excess of 25,000 PSI.

To ensure ROP and durability improvements in tough drilling applications, Tough-Drill bits combine the following technologies to drastically minimize cutter wear:

- Advanced cutting structure (cutter layouts)
- High performance PDC cutters
- Superior hydraulic configurations

With reduced PDC cutter wear, Tough-Drill bits are able to sustain higher penetration rates (ROP) for longer periods of time, thus drilling faster and longer.

Advanced Cutting Structures

Tough-Drill™ bits are designed with Varel's proprietary SPOT™ design software. This tool, developed after extensive single-cutter and full-scale bit tests in laboratory and field conditions, ensures cutting structure optimization for specific applications.

SPOT models complete bit behavior in different rock types during the drilling process. In addition, it evaluates cutter failure as a result of friction and heat transfer. Using appropriate rock geological and mechanical properties, SPOT also performs sensitivity analysis for various drilling parameters (WOB and RPM) to evaluate their effects on ROP, bit wear, vibrations and footage. This process improves the ROP and run length of Tough-Drill bits.

Hydraulics

As part of the product development process, Tough-Drill bits go through elaborate CFD. Re-grinding and re-circulation of drilled cuttings, common occurrences in hard and abrasive applications, are eliminated in this process. In addition, possible stagnation zones are identified and eliminated. This sophisticated process improves cleaning efficiency, cutter cooling and ROP.

Tough-Drill PDC Bits

› Advanced Cutting Structure (Cutter Layout)

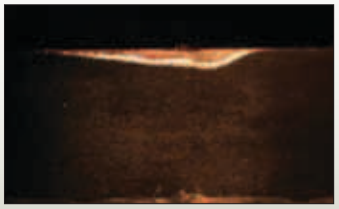
› Superior Hydraulic Configurations

› High Performance PDC Cutters

› Wear Flat Comparison

Wear flat comparison between standard premium cutter and specialized Tough-Drill high abrasion resistance cutter under identical conditions

Standard Premium Bit



Tough-Drill

Diamond Edge Bits

The Diamond Edge™ PDC bit from Varel International provides a unique cutting structure specially equipped for transitional zones and hard rock drilling. This innovative design allows operators to recognize drilling efficiencies through:

- Increased rates of penetration
- Enhanced stability
- Optimum product durability

What is the Diamond Edge drill bit?

The Diamond Edge is a patent pending PDC drill bit designed to run at high penetration rates even in applications that call for higher blade and cutter counts.

Its unique cutting structure layout adds another dimension to bit stability and smooth running by combining the penetration rate potential of traditional “single set” cutter layouts with the life extending features of a “plural set” cutter layout. The result is a bit that runs up to 20 percent faster than plural set PDC bits with minimum bit wear.

How does the cutting structure work?

With Diamond Edge, Varel has extended the advantages of an asymmetric blade cutting structure in the control of bit vibration by adding precisely defined plural cutter blade asymmetry.

This proprietary approach enhances both stability and penetration rate. You get more out of the bit, and more out of the diamond on the bit.

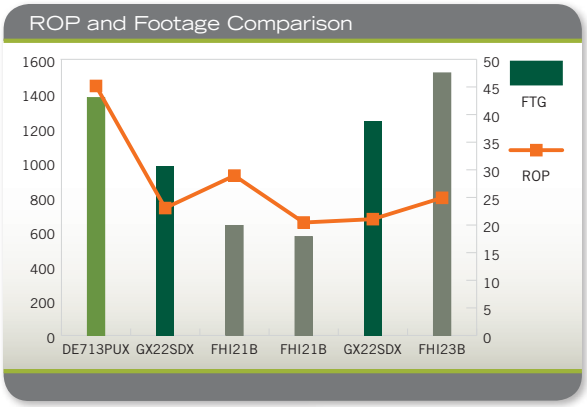
What are the benefits of the new design?

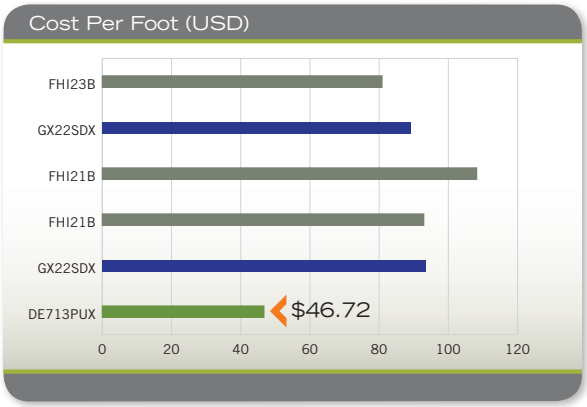
Diamond Edge bits work across an extended range of weight on bit, penetrating quickly even at low bit weights in softer rock. When formations firm up, the bits can take added weight with a smooth torque response and maintain higher than competitive rates of penetration.

The technology is a departure from traditional plural set bits that require higher weights to drill even in soft rock, and are generally durable, but slow, even in harder rock. Traditional plural set bits also can produce an erratic torque response when taking additional weight.

The proof is in the performance!

Diamond Edge Bit Case Studies





Case Study #1

Major Operator – Hill County, Texas
8-3/4" DE713PUX Diamond Edge Bit

Challenge

A major operator drilling in Hill County, Texas, needed a bit that could withstand formations known to be extremely hard and abrasive where roller cone bits have historically been used. Plans in the area called for a kick off deep down hole, requiring a bit that was steerable and durable enough to maintain steerability after enduring abrasive sands. Formation tops are as follows:

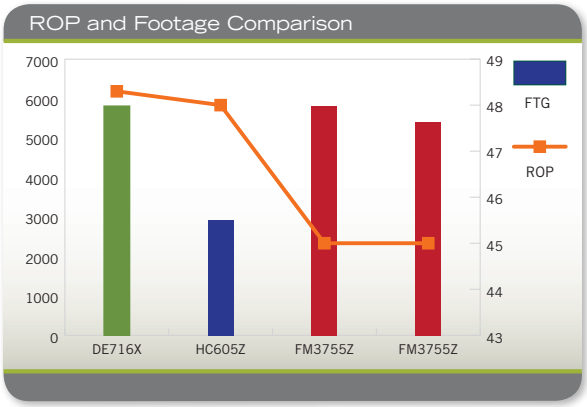
- **Bend Conglomerate 5820-7910 feet, Marble Falls 7910-8100 feet, Barnett 8100-8220 feet**

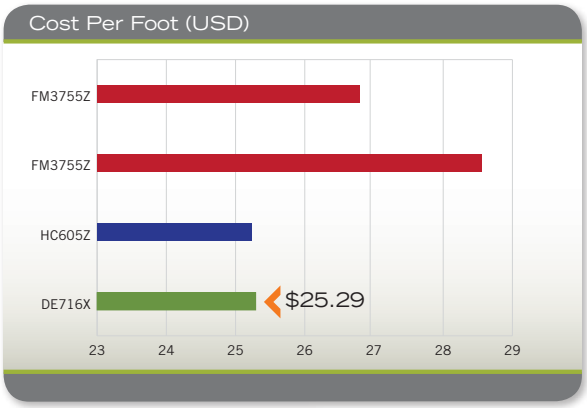
Solution

Varel recommended the DE713PUX Diamond Edge™ PDC bit.

Results

The DE713PUX drilled down to 8,120 feet in 30.5 hours while improving ROP to 45.2 feet per hour. The bit drilled twice as fast as a traditional bit in the section, drilling a typical two-bit interval in just one run.





Case Study #2

Major Operator – Upton County, Texas
7-7/8" DE716X Diamond Edge Bit

Varel International recently recommended a 7-7/8" DE716X Diamond Edge bit to an operator in Upton County, Texas. The bit drilled a total of 5,815 feet to reach the TD of 10,635 feet, with the lowest average weight on bit when compared to other runs in the area.

- **Reached TD in 120.5 hours**
- **Low cost per foot**
- **10 percent reduction in WOB with a 7 percent improvement in ROP**

VB Series Bits

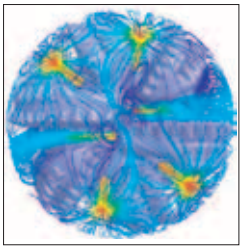
Varel's VB product line is a premium line of matrix bits featuring two very unique features–oval cutters and lateral hydraulic jet nozzles. The VB series is designed to provide better ROP and longer life than bits designed only with conventional round cutters and hydraulic package.

The oval cutter provides more diamond exposure than a round cutter sharing the same diamond width. The sharper tip profile of the oval cutter produces higher point loading, converting applied weight more efficiently than a round cutter, thereby increasing ROP.

The lateral jet nozzles, located near the center of the bit, provide greater efficiencies directing flow across the face of the bit for optimal cleaning and cooling of cutters. Lateral nozzles, in combination with conventional nozzles, produce higher ROP and increased bit life.

Lateral Jet Nozzles

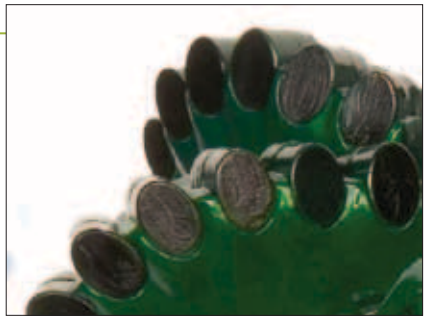
VB bits use lateral jet nozzles located near the center of the bit. These nozzles are oriented in such a way that, when combined with traditional nozzles, create cross flow hydraulics. This cross flow optimizes hydraulic energy, cooling and cleaning of the cutters, enhanced chip removal and efficiently sweeps cuttings away from the bit face into the annulus. This hydraulic configuration promotes faster ROP and reduces cutter wear for longer bit life.



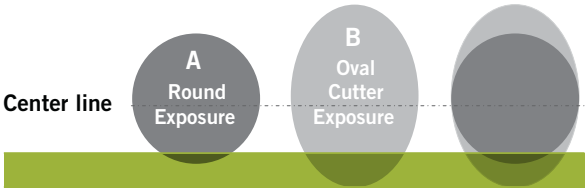
› As part of the product development process, all Varel bits utilize Computational Fluid Dynamics evaluations.

› Oval Cutter

The unique oval cutter design delivers from 43 to 46 percent* more diamond exposure than a round cutter of the same width. Because of its unique shape, the increased exposure provides more footage drilled and improved bit life, helping lower your cost per foot. Additionally, the oval cutter design produces higher point loading converting applied weight on bit more efficiently and dulling with a smaller wear flat than a round cutter of the same width.



› Oval Cutter Advantage

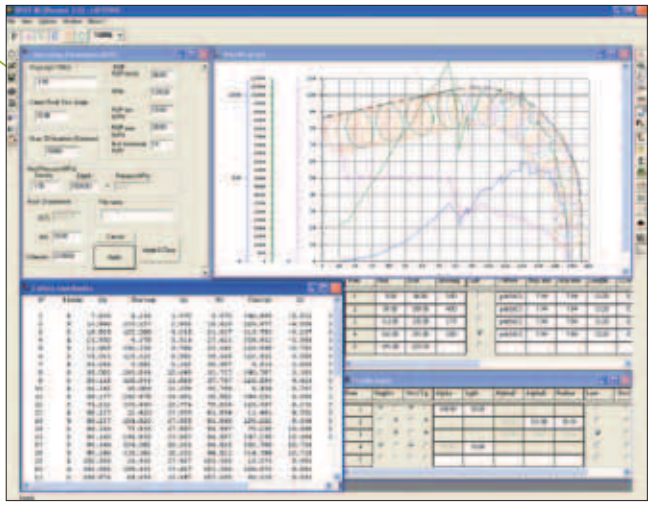


› PowerCutter™ Cutting Structure

Varel's high-density "PowerCutter" arrangement gives enhanced bit life when drilling a variety of rock types without sacrificing ROP. The new PowerCutter cutting structure provides extra exposure and cutter density on the critical shoulder area of the bit. Bits can now achieve maximum rates of penetration through one rock formation and then continue to penetrate harder sand or limestone beds without excessive wear or damage, e.g. interbedded formations.

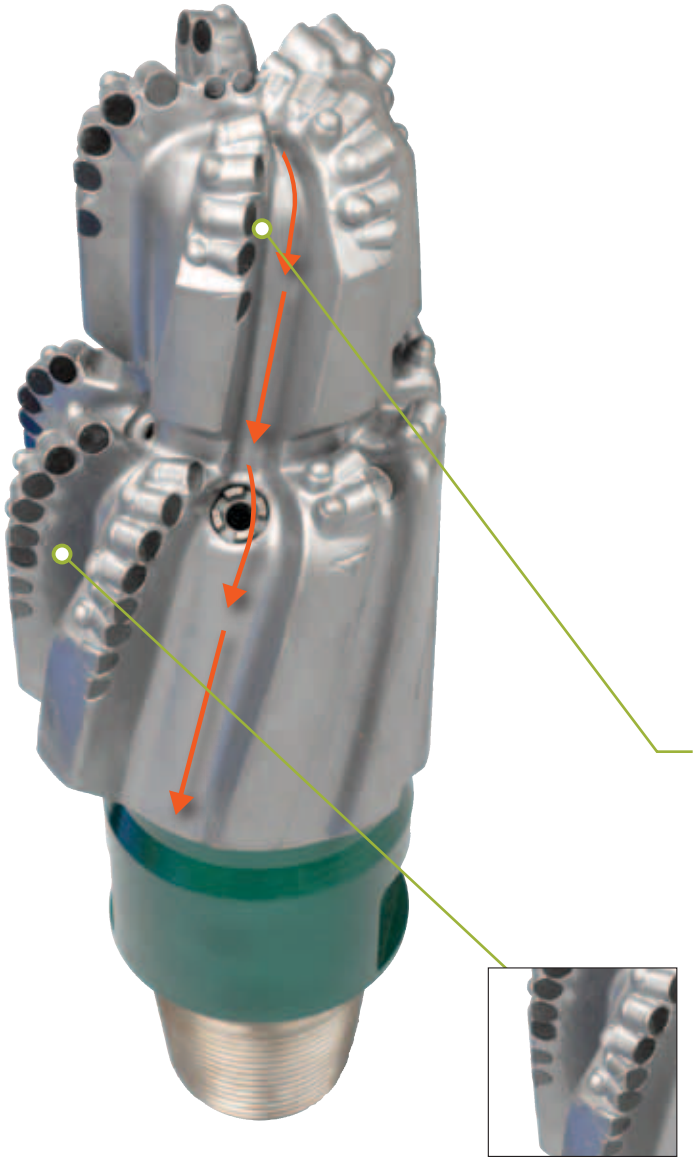
› Advanced Cutting Structure

VB bits are developed using Varel's proprietary design software called SPOT™. Using extensive single cutter tests and full scale bit tests in laboratory and field conditions, SPOT ensures cutting structure optimization for specific applications. SPOT models complete bit behavior in different rock types during a simulated drilling process. In addition, it evaluates cutter wear as a result of friction and heat transfer. Using appropriate rock geology and mechanical properties, SPOT also performs sensitivity analysis for various drilling parameters, i.e., weight on bit, WOB, and revolutions per minute, RPM, to evaluate their effects on ROP, cutter wear, bit vibrations and footage drilled. Using SPOT improves the ROP and increases the footage drilled of each VB bit.



**Based on cutter sizes*

Hole Opening Bits



Varel's bicenter bits are designed to enlarge the wellbore, by drilling 15 to 25 percent larger than the pass through wellbore in all types of PDC drillable formations. The bicenter bits are used to increase lateral diameter, to replace under reaming, to help control trouble zones, and for expandable tubulars. The matrix material construction resists erosion and abrasion found when drilling oilfield applications. The one-piece design shortens the overall bit length for better directional control. Varel bicenter bits also have an innovative force balanced cutting structure that minimizes cutter and casing damage when drilling out. Additionally, Varel's unique design minimizes bit vibrations often experienced with conventional hole opening tools, thereby resulting in longer downhole tool life and reduced drilling costs.

› One-Piece Construction

Varel's unique design shortens the overall bit length for better directional control and eliminates the need to have a connection and weld between the pilot bit and the reamer section of the bicenter. The one-piece construction also allows for optimal hydraulic configuration with pilot and reamer blade alignment, optimizing cuttings removal and improving ROP.

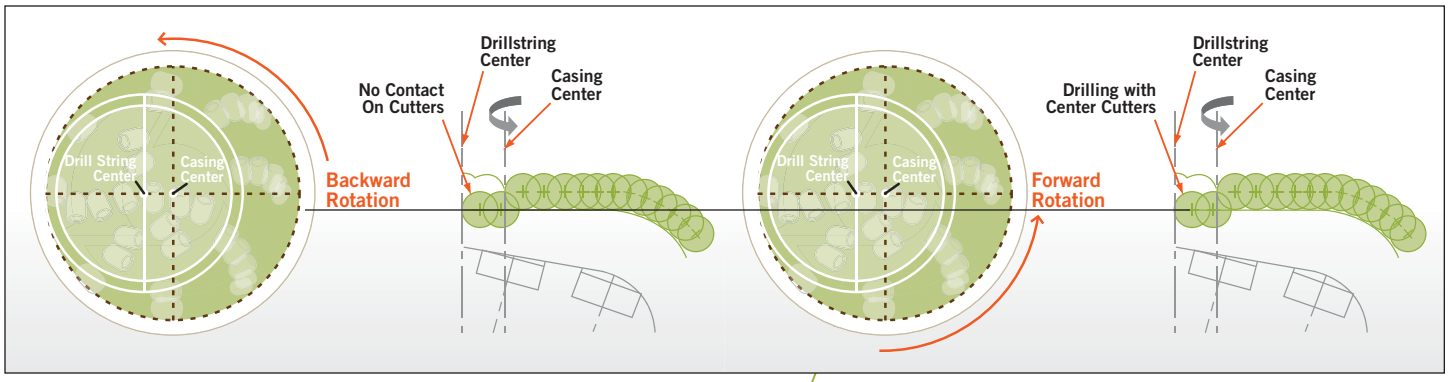
› Hydraulic Design

Nozzle placement, pilot bit and reamer blade alignment provide a direct flow path to the annulus. The junk slot area is maintained or increased, resulting in no decrease in fluid velocity and improved cuttings removal between the pilot and reamer.

› Spiraled Blades

Varel's bicenter bits are designed with spiral blades to provide better contact with the casing during drill out. Spiral blades stabilize the bit ensuring less damage to the casing and resulting in better wellbore quality.

The drill-out feature, designed for Varel's bicenter bit, was recently awarded a Woelfel Best Mechanical Engineering Achievement Merit Award. The annual award, sponsored by American Society of Mechanical Engineers - International Petroleum Institute Petroleum Division (ASME-IPTI), recognizes a product or system that demonstrates a practical solution to an engineering challenge in offshore technology.

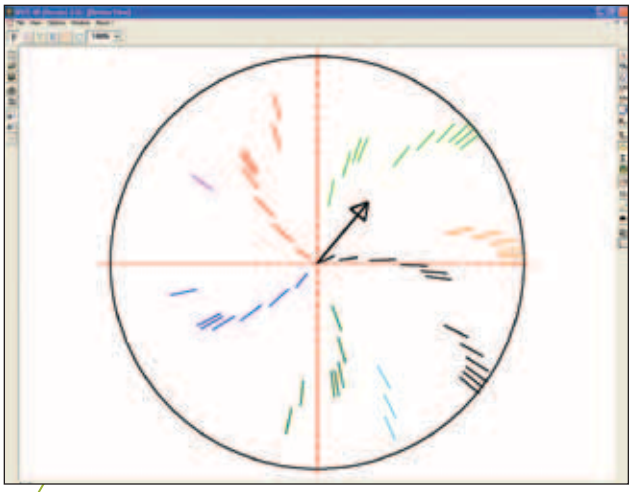


Bicenter Drilling Cement Inside the Casing

Bicenter in Formation

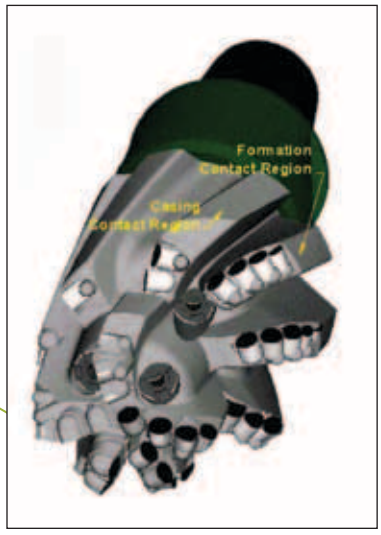
› Cutting Structure Drill Out Feature

Varel's Casing Saver Design cutting structure feature provides a reliable drill out mode while protecting the cutting structure inside the casing. Because of the bicenter bit's unique application, the bit design is not symmetrical. When drilling out from casing, the bit rotates on the casing centerline and not the bit centerline. This off-center rotation of conventional bits can cause damage to cutters located near the center of the pilot bit. This cutter damage is due to backward rotation of cutters located between the bit centerline and the casing centerline in the pilot bit. However, Varel has repositioned cutters between the two centerlines in the nose of the pilot bit. Our design minimizes the possibility of cutter damage while inside the casing in drill-out mode. As the bit transitions to formation drilling, the cutters begin to rotate normally about the bit centerline and cut the formation. This small but unique design philosophy prevents cutter damage when drilling out, allowing efficient rock–cutter interaction during formation drilling.



› Force Balancing

During the design process, the pilot and reamer cutting structure are force balanced as a single unit. This provides increased drilling efficiencies in both vertical and deviated wells. Improved ROP, increased durability and better directional control are all benefits of Varel's force balancing.



› Casing Saver Design

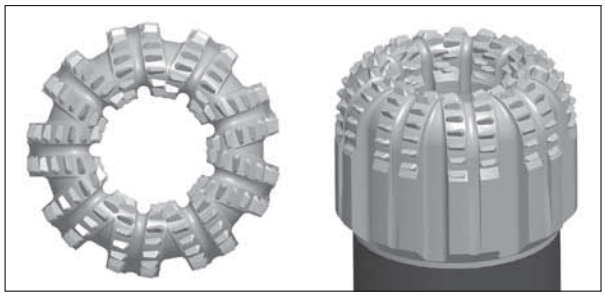
Pilot bit design, spiral blades, non-contact gage cutters and casing saver technology all result in minimal casing damage during drill out.

Specialty Bits: Natural Diamond, TSP and Core Bits

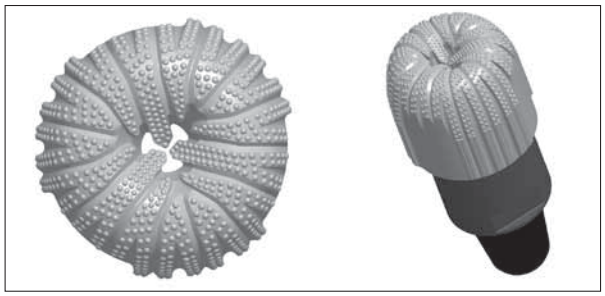
Specialty Bits

Varel offers a variety of bits and core bits manufactured with natural diamond, Thermally Stable Polycrystalline (TSP) and Polycrystalline Diamond Compact (PDC) materials, available for specific drilling applications. All designs are available in matrix with size availability ranging from 4" to 17 ½" (101.6 mm to 444.5 mm).

For additional details, please contact your Varel representative.



CB320



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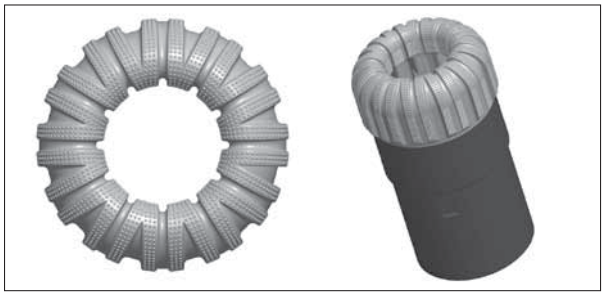

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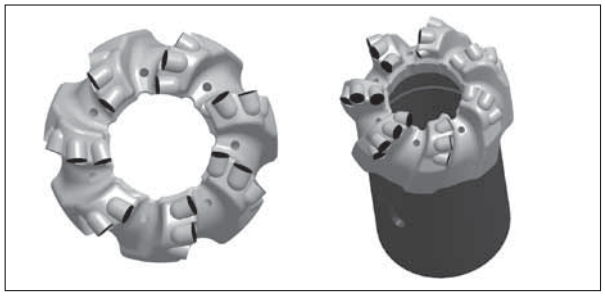

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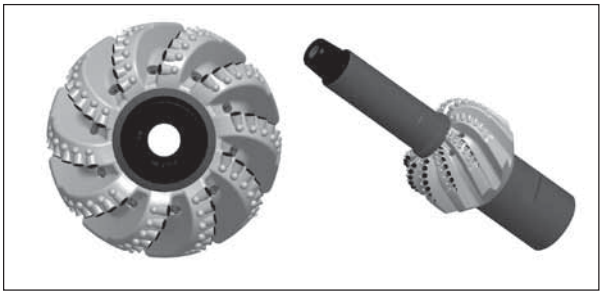
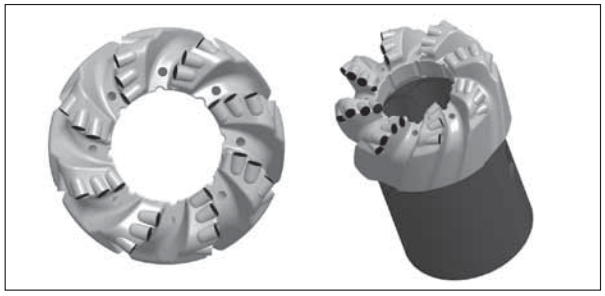


VH10119DGX



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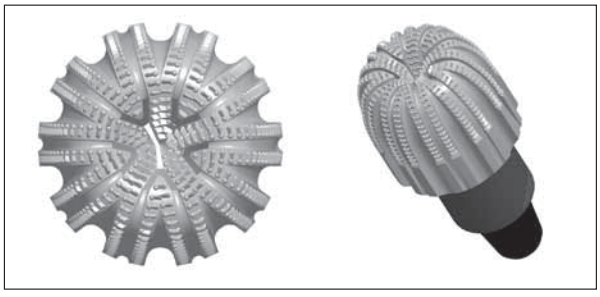

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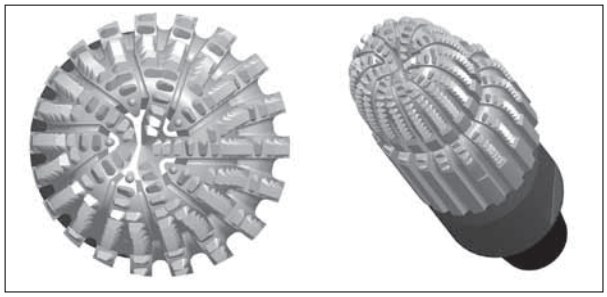
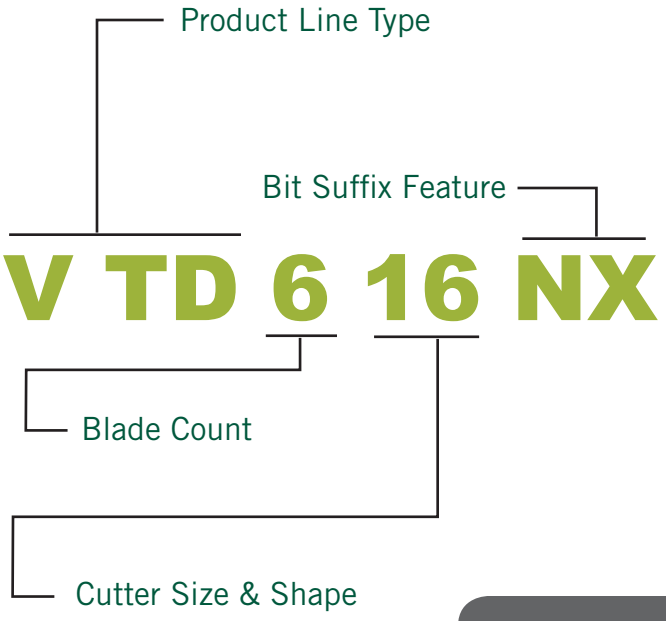


VHP320

Fixed Cutter Bit Nomenclature



VM519
Navigator PDC bit for steerable motor with five blades and 19mm cutters

VTD616PX
Tough-Drill PDC bit with six blades, 16mm cutters, PowerCutter structure and updrill cutters

DE713PUX
Diamond Edge PDC cutter with seven blades, 13mm cutters, PowerCutter structure, updrill cutter and tungsten carbide shock studs

VH813
Bicenter PDC with eight blades and 13mm cutters

VN300
Natural diamond bit for medium hard formations

Product Line Type	Blade Count	Cutter Size (mm) & Shape	Suffix Features
Standard PDC Bit	3	09[1]	S - Steel Body
DE - Diamond Edge	4	13	B - Box Connection
RT - Navigator Point the Bit	5	16	T - Turbine Sleeve
RP - Navigator Push the Bit	6	19	P - PowerCutter Structure (DR no longer exists)
M - Navigator Steerable Motor	7	13 x 9; 90[2]	P2 - Partial PowerCutter Structure
H - Hole Opening Bicenter	8	16 x 11; 110	PP - Triple Row PowerCutter Structure
B - Lateral Jets and Oval Cutters	9	19 x 13; 130	D - Drop in Cutter in Gage Pad
CB - Core Bit	10	23 x 16; 160	G - All TSP Gage
TD - Tough Drill	11	*100	L - Lateral Jets
N - Natural Diamond	12	**300	N - Nozzle Pattern Less Than One Nozzle per Blade
P - TSP		***500	H - Nozzle Pattern in Excess of One Nozzle per Blade
			W - Crown TSP
			U - Up Drill / Back Ream
			X - Tungsten Carbide Shock Studs in All Positions
			R - Diamond Shock Studs (except gage position)

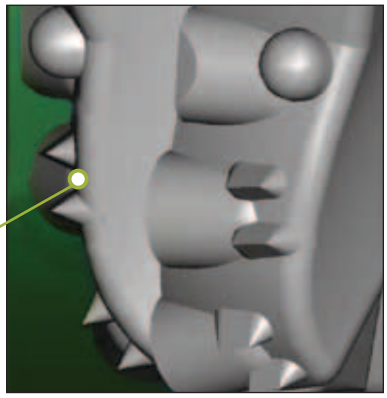
[1] Designates Round Cutters
[2] Designates Oval Cutters
* Soft formation design (N and P product line)
** Medium formation design (N and P product line)
*** Hard formation design (N and P product line)

Fixed Cutter Features

Cutting Structure Features

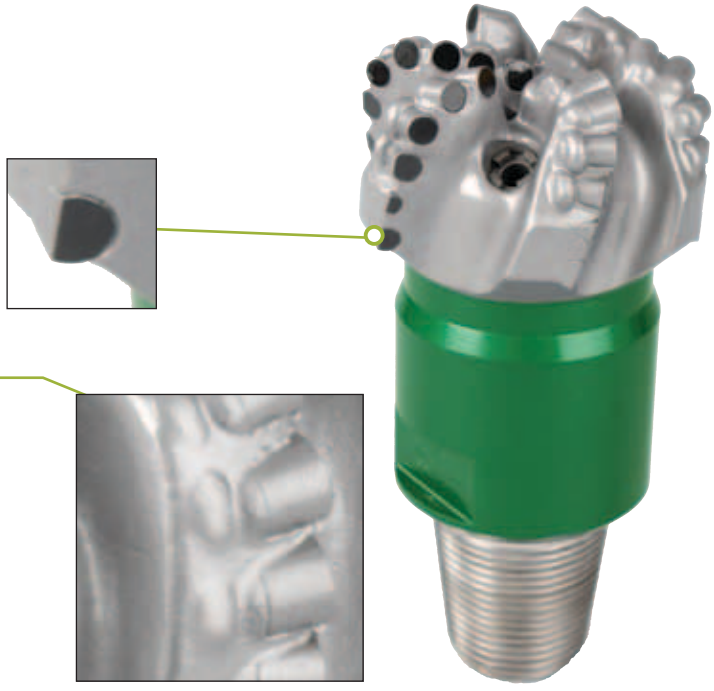
› "P" PowerCutter Cutting Structure

Varel's high-density "PowerCutter" arrangement gives enhanced bit life through a variety of rock types without sacrificing ROP. The new PowerCutter cutting structure provides extra exposure and cutter density on the critical shoulder area of the bit. Bits can now achieve maximum rates of penetration through one rock formation and then continue to penetrate harder sand or limestone beds without excessive wear or damage, e.g., interbedded formations.



› "W" Crown TSP

Thermally Stable Polycrystalline diamond material is beneficially placed behind PDC cutters to improve bit stability with a grooving effect. A unique wear pattern is created increasing PDC cutter indentation as the cutter wears down.



› "U" Updrill / Back Ream

When directional drilling, hole wall sloughing, keyseating, or severe dog legs can occur, requiring action. The updrill feature allows hole wall cleaning as you ream the wellbore, eliminating problems.

› "X" Tungsten Carbide Shock Studs/ "R" Diamond Shock Studs

Shock Studs limit drill bit vibration and increase stability. When drilling conditions cause a vibration, Shock Studs make contact with the formation to help restore the bit's normal smooth cutting action. Smooth cutting action increases cutter life and overall bit performance.

Fixed Cutter Features

Gage Features

"T" Turbine Sleeve

Turbine sleeves can be customized to specific lengths and diameters to match each individual requirement. Sleeves are designed so the junk slots match the bit junk slots eliminating intersections, making the design hydraulically efficient. Gage protection on the sleeve can also be matched to the customer's need.

"G" Premium Gage

Premium gage protection is designed to ensure that correct hole diameter is maintained. A variety of gage configurations exist. The premium gage consists of Thermally Stable Polycrystalline diamond rounds, Tungsten Carbide bricks and PDC (Polycrystalline Diamond Compact) cutters. The number of pre-flat PDC cutters in the gage is the only option with this feature.

Hydraulics Options

"L" Lateral Jet Nozzles

Varel bits can use highly angled lateral nozzles located near the center of the bit in combination with traditional nozzles to create cross flow hydraulics. This cross flow optimizes hydraulic energy, cooling and cleaning of the cutters, enhanced chip removal, efficiently sweeping cuttings away from the bit face into the annulus. This hydraulic configuration promotes faster ROP and reduces cutter wear for longer bit life.

"N" Nozzle Pattern

With the "N" feature, a bit will have less than one nozzle per blade. The number of nozzles will be determined by the application or bit design. Typical nozzle pattern is one nozzle per blade.

"H" Nozzle Pattern

With the "H" feature, a bit will have more than one nozzle per blade. The number of nozzles will be determined by the application or bit design. Typical nozzle pattern is one nozzle per blade.

Fixed Cutter Features

Other Features

› "S" Steel Body

Steel body drill bit designs are typically used in applications where open-faced hydraulics and aggressive cutting structures are required. They can provide for faster penetrating bits than conventional matrix designs.

› "B" Box Connection

Box connections are most commonly used in conjunction with a turbine sleeve so that crossover subs are not required when connecting to turbines, RSS and other downhole tools.

› Short Shank Bit

A shorter shank bit is characteristic of our Navigator product line for added directional responsiveness.

Nozzle Series

Diameter in.	mm	Nozzle Series		
		50	55	65
9/32	7.14	•	•	•
10/32	7.94	•	•	•
11/32	8.73	•	•	•
12/32	9.53	•	•	•
13/32	10.32	•	•	•
14/32	11.11	•	•	•
15/32	11.91	•	•	•
16/32	12.70	•	•	•
17/32	13.49		•	•
18/32	14.29		•	•
19/32	15.08			•
20/32	15.88			•
21/32	16.67			•
22/32	17.46			•

Fixed Cutter Gage Diamond Tolerances

Diamond Drilling, Diamond Core, and PDC Bit Tolerances

Bit Size, OD in.	OD Tolerances in.	mm
6 3/4 and smaller	+ 0 - 0.015	+ 0 - 0.38
6 25/32 to 9 inclusive	+ 0 - 0.020	+ 0 - 0.51
9 1/32 to 13 3/4 inclusive	+ 0 - 0.030	+ 0 - 0.76
13 25/32 to 17 1/2 inclusive	+ 0 - 0.045	+ 0 - 1.14
17 17/32 and larger	+ 0 - 0.063	+ 0 - 1.60

Make-up Torque

Connection In.	Pin ID In.	Bit Sub Od In.	Make-Up Torque Ft.-Lbs.	
			Mini	Maxi
2-3/8 API REG	1	3	1800	2000
		3-1/8 and larger	2400	2700
2-7/8 API REG	1-1/4	3-1/2	3100	3400
		3-3/4	4600	5100
		3-7/8	4700	
3-1/2 API REG	1-1/2	4-1/8	5200	5700
		4-1/4	6300	6900
		4-1/2	7700	8400
		4-3/4	7800	8600
4-1/2 API REG	2-1/4	5-1/2	12500	13700
		5-3/4	16500	16700
		6 and larger	17600	
6-5/8 API REG	3	7-1/2	37100	40800
		7-3/4 and larger	40800	
7-5/8 API REG	3-1/2	8-1/2	48300	53200
		8-3/4	57700	63500
		9	63800	65200
		9-1/4	64300	65700
		9-1/2	64800	66200

Make-up Torque Box Connection

Connection In.	Bit Od In.	Make-Up Torque Ft.-Lbs.	
		Mini	Maxi
3-1/2 API IF	5 5/8 - 6 1/8	3700	4000
4-1/2 API IF	8 3/8 - 8 3/4	23400	25700
6-5/8 API REG	12 1/4	37100	40800
	16 - 17 1/2	43500	44100

Diamond Drill Bit and PDC Bit Connection

Size of Bit in.	Size & Stlye of Rotary Pin Connection	Bit Sub Bevel Dia.^a inches +/- 1/64	millimeters +/- 0.40	Bit Bevel Dis. ^a. inches +/- 1-64	millimeters +/- 0.40
1.75 to 2.24 inclusive	1 reg^b	1.500	38.10	1.532	38.91
2.25 to 3.49 inclusive	1 1/2 reg^c	1.932	49.07	1.964	49.89
3.50 to 4.5 inclusive	2 3/8 reg	3.047	77.39	3.078	78.18
4 17/32 to 5 inclusive	2 7/8 reg	3 39/64	91.68	3 41/64	93.66
5 1/32 to 7 3/8 inclusive	3 1/2 reg	4 7/64	104.38	4 9/64	105.17
7 13/32 to 9 3/8 inclusive	4 1/2 reg	5 21/64	135.33	5 23/64	136.13
9 13/32 to 14 1/2 inclusive	6 5/8 reg	7 23/64	186.93	7 25/64	187.72
14 9/16 to 18 1/2 inclusive	6 5/8 reg or 7 5/8 reg	7 23/64 or 8 15/32	186.93 or 215.11	7 25/64 or 8 1/2	187.72 or 215.90
18 9/16 and larger	7 5/8 reg or 8 5/8 reg	8 15/32 or 35/64	215.11 or 242.49	8 1/2 or 9 37/64	218.90 or 243.28

Nozzle Total Flow Area

Nozzle Total Flow Area (TFA) Table

Nozzle Size	Nozzle Flow Area (square inches)									
	1 Nozzle	2 Nozzles	3 Nozzles	4 Nozzles	5 Nozzles	6 Nozzles	7 Nozzles	8 Nozzles	9 Nozzles	10 Nozzles
7/32	0.0375	0.0751	0.1127	0.1503	0.1879	0.2254	0.2630	0.3006	0.3382	0.3758
8/32	0.0490	0.0981	0.1472	0.1963	0.2454	0.2945	0.3436	0.3926	0.4417	0.4908
9/32	0.0621	0.1242	0.1863	0.2485	0.3106	0.3727	0.4348	0.4970	0.5591	0.6212
10/32	0.0766	0.1533	0.2300	0.3067	0.3834	0.4601	0.5368	0.6135	0.6902	0.7669
11/32	0.0928	0.1856	0.2784	0.3712	0.4640	0.5568	0.6496	0.7424	0.8352	0.9280
12/32	0.1104	0.2208	0.3313	0.4417	0.5522	0.6626	0.7731	0.8835	0.9940	1.1044
13/32	0.1296	0.2592	0.3888	0.5184	0.6481	0.7777	0.9073	1.0369	1.1665	1.2962
14/32	0.1503	0.3006	0.4509	0.6013	0.7516	0.9019	1.0523	1.2026	1.3529	1.5032
15/32	0.1725	0.3451	0.5177	0.6902	0.8628	1.0354	1.2080	1.3805	1.5531	1.7257
16/32	0.1963	0.3926	0.5890	0.7853	0.9817	1.1780	1.3744	1.5707	1.7671	1.9634
18/32	0.2485	0.4970	0.7455	0.9940	1.2425	1.4910	1.7395	1.9880	2.2365	2.4850
20/32	0.3067	0.6135	0.9203	1.2271	1.5339	1.8407	2.1475	2.4543	2.7611	3.0679
22/32	0.3712	0.7424	1.1136	1.4848	1.8561	2.2273	2.5985	2.9697	3.3410	3.7122
24/32	0.4417	0.8835	1.3253	1.7671	2.2089	2.6507	3.0925	3.5342	3.9760	4.4178
26/32	0.5184	1.0369	1.5554	2.0739	2.5924	3.1109	3.6293	4.1478	4.6663	5.1848
28/32	0.6013	1.2026	1.8039	2.4052	3.0065	3.6079	4.2092	4.8105	5.4118	6.0131

API Casing Dimensions and Bit Diameters

Dimensions						Bit Size	
Size OD in.	Weight Per Foot Nominal lbs.	Wall Thickness in.	Nominal Inside Diameter in.	Casing Coupling OD in.	API Drift Diameter in.	Recommended Bit Size Diameter in.	mm
4 1/2	9.50	.205	4.090	5.000	3.965	3 7/8	98.4
	10.50	.224	4.052	5.000	3.927	3 7/8	98.4
	11.60	.250	4.000	5.000	3.875	3 7/8	98.4
	13.50	.290	3.920	5.000	3.795	3 3/4	95.2
5	11.50	.220	4.560	5.563	4.435	4 1/4	107.9
	13.00	.253	4.494	5.563	4.369	4 1/4	107.9
	15.00	.296	4.408	5.563	4.283	4 1/4	107.9
	18.00	.362	4.276	5.563	4.151	4 1/8	104.8
5 1/2	14.00	.244	5.012	6.050	4.887	4 7/8	123.8
	15.50	.275	4.950	6.050	4.825	4 3/4	120.7
	17.00	.304	4.892	6.050	4.767	4 3/4	120.7
	20.00	.361	4.778	6.050	4.653	4 5/8	117.5
	23.00	.415	4.670	6.050	4.545	4 1/2	114.3
6 5/8	20.00	.288	6.049	7.390	5.924	5 7/8	149.2
	24.00	.352	5.921	7.390	5.796	5 3/4	146.1
	28.00	.417	5.791	7.390	5.666	5 5/8	142.8
	32.00	.475	5.675	7.390	5.550	5 1/4	133.4
7	17.00	.231	6.538	7.656	6.413	6 1/4	158.7
	20.00	.272	6.456	7.656	6.331	6 1/4	158.7
	23.00	.317	6.366	7.656	6.241	6 1/4	158.7
	26.00	.362	6.276	7.656	6.151	6 1/8	155.5
	29.00	.408	6.184	7.656	6.059	6	152.4
	32.00	.453	6.094	7.656	5.969	5 7/8	149.2
	35.00	.498	6.004	7.656	5.879	5 7/8	149.2
	38.00	.540	5.92	7.656	5.795	5 3/4	146.1
7 5/8	24.00	.300	7.025	8.500	6.900	6 3/4	171.4
	26.20	.328	6.969	8.500	6.844	6 3/4	171.4
	29.70	.375	6.875	8.500	6.750	6 3/4	171.4
	33.70	.430	6.765	8.500	6.640	6 1/2	165.1
	39.00	.500	6.625	8.500	6.500	6 1/2	165.1
8 5/8	24.00	.264	8.097	9.625	7.972	7 7/8	200.0
	28.00	.304	8.017	9.625	7.892	7 7/8	200.0
	32.00	.352	7.921	9.625	7.796	7 5/8	193.7
	36.00	.400	7.825	9.625	7.700	7 5/8	193.7
	40.00	.450	7.725	9.625	7.600	6 3/4	171.4
	44.00	.500	7.625	9.625	7.500	6 3/4	171.4
	49.00	.557	7.511	9.625	7.386	6 3/4	171.4
9 5/8	32.30	.312	9.001	10.635	8.845	8 3/4	222.2
	36.00	.352	8.921	10.635	8.765	8 3/4	222.2
	40.00	.395	8.835	10.635	8.679	8 1/2	215.9
	43.50	.435	8.755	10.635	8.599	8 1/2	215.9
	47.00	.472	8.681	10.635	8.525	8 1/2	215.9
	53.50	.545	8.535	10.635	8.379	8 3/8	212.7
10 3/4	32.75	.279	10.192	11.750	10.036	9 7/8	250.8
	40.50	.350	10.050	11.750	9.894	9 7/8	250.8
	45.50	.400	9.950	11.750	9.794	9 5/8	244.5
	51.00	.450	9.850	11.750	9.694	9 5/8	244.5
	55.50	.495	9.760	11.750	9.604	9 1/2	241.3
	60.70	.545	9.660	11.750	9.504	9 1/2	241.3
	65.70	.595	9.560	11.750	9.404	9	228.6
11 3/4	42.00	.333	11.084	12.750	10.928	10 5/8	269.9
	47.00	.375	11.000	12.750	10.844	10 5/8	269.9
	54.00	.435	10.880	12.750	10.724	10 5/8	269.9
	60.00	.489	10.772	12.750	10.616	9 7/8	250.8
13 3/8	48.00	.330	12.715	14.375	12.559	12 1/4	311.1
	54.50	.380	12.615	14.375	12.459	12 1/4	311.1
	61.00	.430	12.515	14.375	12.359	12 1/4	311.1
	68.00	.480	12.415	14.375	12.259	12 1/4	311.1
	72.00	.514	12.347	14.375	12.191	12	304.8
16	65.00	.375	15.250	17.000	15.062	14 3/4	374.6
	75.00	.438	15.125	17.000	14.936	14 3/4	374.6
	84.00	.495	15.010	17.000	14.822	14 3/4	374.6
18 5/8	87.50	.435	17.756	20.000	17.567	17 1/2	444.5
20	94.00	.438	19.124	21.000	18.936	17 1/2	444.5
	106.50	.500	19.000	21.000	18.812	17 1/2	444.5
	133.00	.635	18.730	21.000	18.542	17 1/2	444.5

Drill Collar Weights

Drill Collar Weights - Suspended in Water

Collar OD	Collar Bore											
	1 1/2	1 1/4	2	2 1/4	2 1/2	2 3/4	2 7/8	3	3 1/4	3 1/2	3 3/4	4
3 3/4	**28** 830	**26** 770										
4	**32** 960	**30** 900										
4 1/4	**37** 1110	**35** 1040	**33** 980									
4 1/2	**42** 1260	**40** 1200	**38** 1130	**35** 1060	**33** 980							
4 3/4	**47** 1420	**45** 1360	**43** 1300	**41** 1220	**38** 1140							
5	**52** 1570	**51** 1530	**49** 1470	**46** 1390	**44** 1310							
5 1/4	**59** 1770	**57** 1710	**55** 1650	**52** 1570	**50** 1490	**47** 1400						
5 1/2	**65** 1950	**63** 1900	**61** 1830	**59** 1760	**56** 1680	**53** 1580						
5 3/4	**72** 2150	**70** 2090	**68** 2030	**65** 1960	**62** 1870	**59** 1780	**58** 1730	**56** 1680				
6	**78** 2330	**77** 2300	**74** 2230	**72** 2160	**69** 2080	**66** 1980	**65** 1930	**63** 1880	**59** 1770			
6 1/4	**86** 2570	**84** 2510	**82** 2450	**79** 2370	**76** 2290	**73** 2200	**72** 2150	**70** 2100	**66** 1990			
6 1/2	**93** 2790	**91** 2740	**89** 2670	**87** 2600	**84** 2510	**81** 2420	**79** 2370	**77** 2320	**74** 2210	**70** 2080	**65** 1960	
6 3/4	**101** 3020	**99** 3000	**97** 2900	**94** 2830	**92** 2740	**88** 2650	**87** 2600	**85** 2550	**81** 2440	**78** 2330	**73** 2200	
7	**109** 3260	**107** 3200	**105** 3140	**102** 3070	**100** 2980	**96** 2890	**95** 2840	**93** 2790	**89** 2680	**86** 2570	**81** 2440	**77** 2300
7 1/4	**117** 3500	**115** 3450	**113** 3380	**110** 3300	**108** 3220	**104** 3130	**103** 3080	**101** 3030	**97** 2920	**94** 2800	**89** 2680	**85** 2540
7 1/2	**126** 3770	**124** 3710	**122** 3650	**119** 3570	**116** 3490	**113** 3400	**112** 3350	**110** 3300	**106** 3190	**102** 3070	**98** 2940	**94** 2800
7 3/4	**134** 4030	**133** 3980	**130** 3910	**128** 3840	**125** 3760	**122** 3660	**121** 3610	**119** 3560	**115** 3450	**111** 3340	**107** 3210	**103** 3070
8	**144** 4310	**142** 4250	**140** 4190	**137** 4110	**134** 4030	**131** 3940	**130** 3890	**128** 3840	**124** 3730	**120** 3610	**116** 3480	**112** 3350
8 1/4		**151** 4540	**149** 4470	**147** 4400	**144** 4310	**141** 4220	**139** 4170	**137** 4180	**134** 4010	**130** 3900	**126** 3770	**121** 3630
8 1/2			**159** 4540	**156** 4690	**154** 4610	**150** 4510	**143** 4460	**147** 4410	**143** 4300	**140** 4190	**135** 4060	**131** 3920
8 3/4			**169** 5620	**166** 4990	**164** 4910	**160** 4810	**159** 4760	**157** 4710	**153** 4600	**150** 4490	**145** 4360	**141** 4220
9				**177** 5300	**174** 5820	**171** 5120	**169** 5070	**168** 5020	**164** 4910	**160** 4800	**156** 4670	**151** 4530
9 1/4				**187** 5620	**185** 5530	**181** 5440	**180** 5390	**178** 5340	**174** 5230	**171** 5120	**166** 4990	**162** 4850
9 1/2					**195** 5860	**192** 5770	**191** 5720	**187** 5670	**185** 5560	**181** 5440	**177** 5310	**173** 5180
9 3/4					**207** 6200	**204** 6100	**202** 6060	**200** 6000	**197** 5900	**193** 5780	**188** 5650	**184** 5510
10					**218** 6540	**215** 6450	**213** 6400	**212** 6350	**208** 6240	**204** 6180	**200** 6000	**195** 5860
10 1/4						**227** 6800	**225** 6750	**223** 6700	**220** 6590	**216** 6480	**212** 6350	**207** 6210
10 1/2						**239** 7160	**237** 7120	**236** 7060	**232** 6960	**228** 6840	**224** 6710	**219** 6580
10 3/4						**251** 7530	**250** 7490	**248** 7430	**244** 7330	**240** 7210	**236** 7080	**232** 6950
11							**262** 7860	**261** 7810	**257** 7710	**253** 7590	**249** 7460	**244** 7330
11 1/4							**275** 8250	**273** 8200	**270** 8090	**266** 7980	**268** 7850	**257** 7710

Pounds-Per-Foot (Bold)
Pounds-Per-30 Foot Collar
Weights per foot rounded off to nearest pound
Weights per 30 foot collar rounded off to nearest 10 pounds

Conversion Formulas

FROM	TO	MULTIPLY BY
	VOLUME	
Barrels	Gallons	42
Cubic Centimeters	Cubic Feet	3.531×10^{-5}
Cubic Centimeters	Cubic Inches	0.06102
Cubic Centimeters	Cubic Meters	10^{-6}
Cubic Centimeters	Gallons	2.642×10^{-4}
Cubic Centimeters	Liters	0.001
Cubic Feet	Cubic Centimeters	28317
Cubic Feet	Cubic Inches	1728
Cubic Feet	Cubic Meters	0.02832
Cubic Feet	Gallons	7.48
Cubic Feet	Liters	28.32
Cubic Inches	Cubic Centimeters	16.39
Cubic Inches	Cubic Feet	5.787×10^{-4}
Cubic Inches	Cubic Meters	1.639×10^{-5}
Cubic Inches	Gallons	4.329×10^{-3}
Cubic Inches	Liters	0.01639
Cubic Meters	Cubic Centimeters	10^{6}
Cubic Meters	Cubic Feet	35.31
Cubic Meters	Gallons	264. 2
Gallons	Barrels	0.0238
Gallons	Cubic Centimeters	3785
Gallons	Cubic Feet	0.1337
Gallons	Cubic Inches	231
Gallons	Cubic Meters	3.785×10^{-5}
Gallons	Liters	3.785
	MASS	
Pounds	Tons (metric)	4.536×10^{-4}
Tons (metric)	Pounds	2204
Tons (metric)	Kilograms	1000

Equations Used in Hydraulic Calculations:

1. Annular Velocity

$$V = \frac{24.5\,Q}{(D_h)^2 - (D_p)^2}$$

2. Surface Equipment Pressure Losses

$$\Delta P = C\rho\left(\frac{Q}{100}\right)^{1.86}$$

Type Equipment	C
1	1.0
2	0.36
3	0.22
4	0.15

3. Drill Stem Bore Pressure Losses

$$\Delta P = \frac{0.000061\,\rho\,LQ^{1.86}}{d^{4.86}}$$

4. Jet Nozzle Pressure Losses

$$\Delta P = \frac{\rho\,Q^2}{10858\,(A_\eta)^2}$$

5. Annular Pressure Losses

$$\Delta P = \frac{(1.4327 \times 10^{7})\rho L V^2}{Dh - Dp}$$

6. Jet Velocity

$$V\eta = \frac{0.32086\,Q}{A_\eta}$$

7. Jet Impact Force

$$I_f = 0.000516\rho Q V_\eta$$

8. Hydraulic Horsepower

$$HH_p = \frac{PQ}{1714}$$

Nomenclature:

Q = Circulation Rate (gpm)
Dh = Diameter of Hole (in)
Dp = Diameter of Pipe O.D. (in)
V = Annular Velocity (ft/min)
ρ = Mud Weight (lb/gal)
C = Friction Factor
P = Pressure (psi)
L = Length (ft)
Aη = Area of Nozzle (in^2)
ΔP = Pressure Drop (psi)
Vη = Jet Velocity (ft/sec)
I_f = Jet Impact Force (lbf)
HHp = Hydraulic Horsepower (hp)
d = Inside Diameter (in)

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CERTIFIED QUALITY MANAGEMENT SYSTEM ISO 9001:2008
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MKTG 11C500-06-2011

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