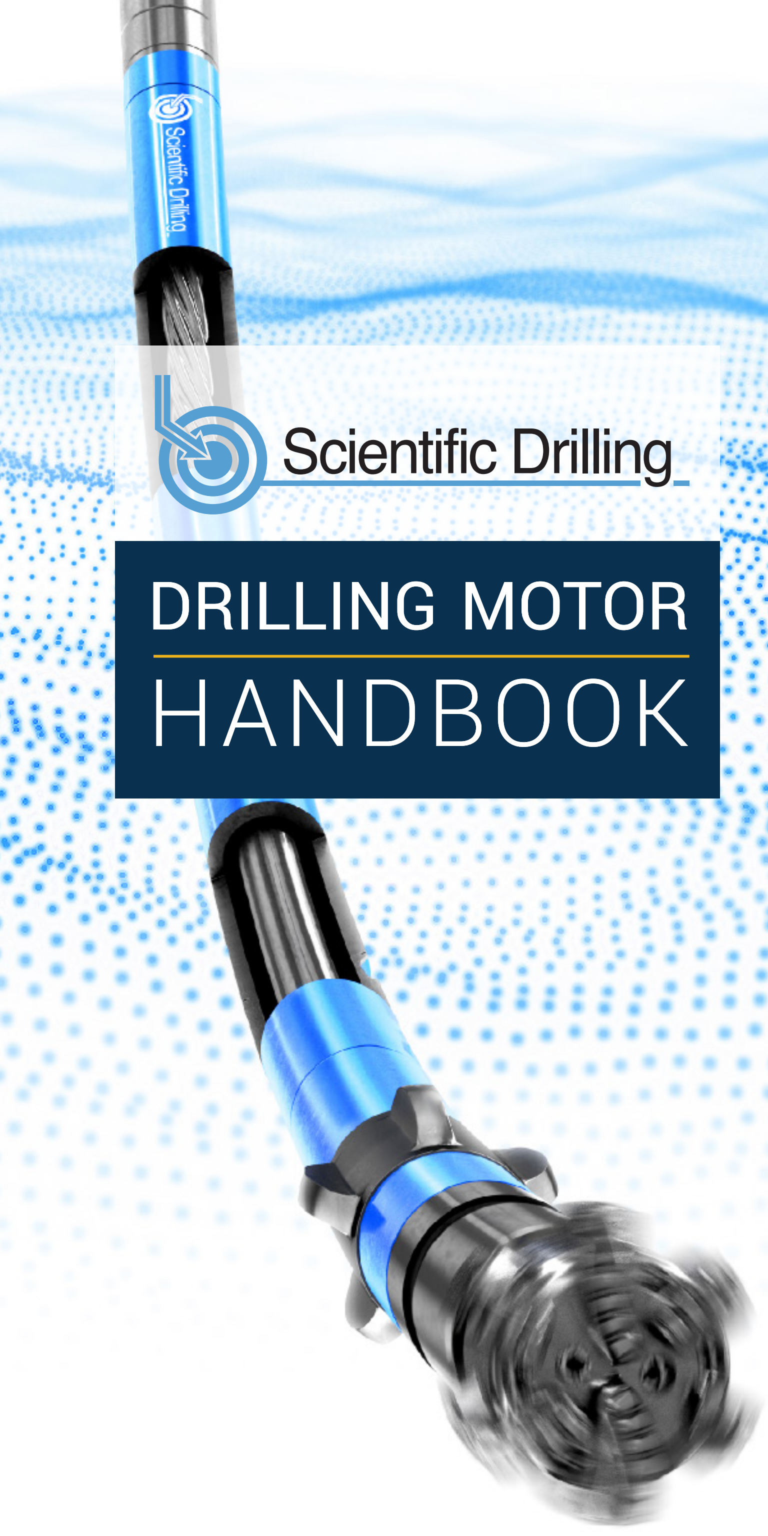
Scientific Drilling

DRILLING MOTOR HANDBOOK



THE ULTIMATE PARTNER IN WELLBORE PLACEMENT

Scientific Drilling International (SDI) is an independent service provider offering a complete high accuracy wellbore placement and drilling solution. We are globally positioned to support a wide range of markets including Oil & Gas, CBM/CSG, Geothermal, and Mining Industries.

We are committed to make it easy for our customers to do business, by providing exemplary service and innovative technology. We earn loyalty one job at a time. We match the right crew to each assignment, and we hold ourselves accountable to the highest standard of quality.

We provide a full suite of drilling technology and services:

- Directional Drilling
- MWD/LWD Services
- Magnetic Ranging
- Drilling Motor Services
- Wellbore Surveying
- Rotary Steerable Services
- Well Planning
- Survey Management
- Drilling Engineering
- Cased Hole Services

PREFACE

This handbook is to be used as a guideline, as it contains general information about SDI's drilling motors and industry accepted operational procedures only, and not suited for every drilling environment. It is intended to familiarize the end user about working principles of SDI's drilling motors and their specifications.

SDI is committed to continuous improvements of the drilling motors and procedures.

To view the most recent version visit:
www.scientificdrilling.com/motorhandbook.

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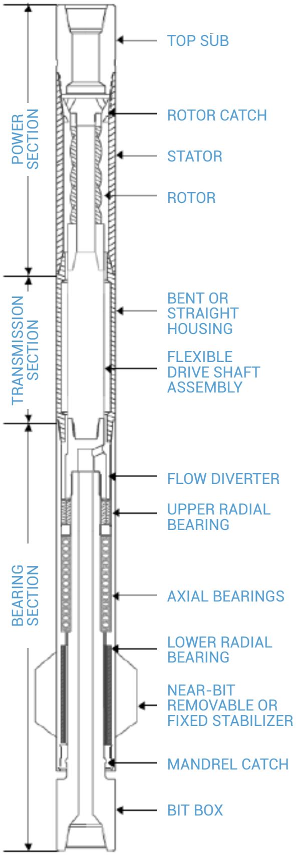
02 MOTOR DESCRIPTION

This section of the handbook is designed to provide the drillers and operators with a general description of SDI's drilling motors. Different motor configurations have varying performance characteristics, but share the same major components:

- Top Sub
- Rotor Catch Mandrel
- Power Section
- Flexible Transmission
- Bent (Transmission) Housing
- Bearing Pack Assembly
- Bit Box
- Near-Bit Stabilizers

FIGURE 1. MOTOR COMPONENTS



TOP SUB

The top sub is utilized to house the rotor catch and bored for a float. If a dump sub is present, it is primarily used to prevent tripping out with a wet drill string and can be used in place of the top sub for an additional charge.

ROTOR CATCH SYSTEM

The rotor catch system consists of components that are installed into the top portion of the motor. The function of the catch system is to minimize the possibility of losing motor components in the hole if a catastrophic failure occurs.

An external motor connection failure causes a substantial pressure loss while on-bottom. In the event of a parted motor, the Bottom Hole Assembly (BHA) is picked up off-bottom and the catch system will activate. It will hold the separated motor together and cause a pressure spike to indicate to drilling personnel that the motor may be damaged. The motor should be tripped out immediately without over-pull or string rotation to improve the chances of successfully tripping out the entire motor.

POWER SECTION

The power section components include the rotor and the stator, which converts hydraulic energy of the drilling fluid into rotational horsepower as the fluid is pumped from surface.

The rotor is a long spiral shaft designed to fit inside a corresponding stator. It is manufactured from a solid bar of stainless steel and plated with hard industrial chrome or carbide coating. The coating protects the parent metal against corrosion and reduces the friction between the rotor and the stator.

The stator is the non-rotating member of the power section. It is made out of a seamless, heat-treated tube with an elastomer lining. The internal cavity of the liner has a spiral geometry designed to accept a rotor of compatible geometry and size. In a positive displacement power section, the rotor always has one less lobe than the stator. SDI offers specially designed elastomers to improve downhole performance.

When the rotor is inserted inside the stator, a certain number of cavities are formed along the length of the power section. The interference between the rotor and the stator lining seals these cavities. During the drilling operation, high pressure drilling fluid is forced through the cavities, causing the rotor to turn inside the stator. The geometrical characteristics of the rotor and the stator offset their longitudinal axes. In other words, the rotor has an eccentric motion inside the stator.

Power sections are categorized by size, rotor/stator lobe ratios, and the number of stages. Figure 2 (below) shows the cross-sectional view of the rotor and the stator profile with different lobe ratios.

FIGURE 2. ROTOR AND STATOR PROFILE

The following guidelines are suggested when selecting and operating any SDI motor:

- The rotational speed of the rotor is proportional to the rate of fluid flow through the power section
- The generated torque is proportional to the differential pressure across the power section
- Power sections with a higher lobe ratio generate more torque and have slower rotary speed than the ones with a lower lobe ratio. For example, a 9⅝" motor with a 5/6 lobe ratio will rotate the drill bit at a higher RPM and will have less output torque per stage than a 9⅝" motor with a 7/8 lobe ratio
- An increase in the stage length will proportionally increase the output torque capability with a resultant slower RPM at the same flow rate

FLEXIBLE TRANSMISSION

The flexible transmission is the link between the rotor and the bearing mandrel, which converts the eccentric motion of the rotor into the smooth concentric rotary motion of the bearing mandrel. It also transmits the torque and rotary motion, generated by the power section, to the drive shaft. The hydraulic down thrust of the rotor is also transferred to the bearing section through this component.

SDI's flexible transmission is manufactured from a high grade of heat-treated alloy. The rugged design of this critical component may incorporate a seal, dependent on lower end configuration.

BENT (TRANSMISSION) HOUSING

This component of the motor houses the flexible transmission coupling and connects the stator housing to the bearing housing. A specific bend amount, ranging from zero to three degrees (0°-3°), is machined into this housing to make the motor assembly steerable.

The bent housing is manufactured using a premium grade of alloy steel. Its contact surface with the formation is hard-faced to minimize wear during the drilling operation.

An adjustable bent housing may be used in place of the fixed bent housing. The adjustable bent housing allows the operator to change the bend of the motor from zero to three degrees (0°-3°) on location.

BEARING ASSEMBLY

The main components of the bearing assembly consist of the bearing mandrel, standard roller thrust bearings and PDC thrust bearings, radial bearings, and flow diverter.

The bearing mandrel is a shaft designed to transmit the power and channel the drilling fluid to the drill bit. It is manufactured from a high grade of alloy and is heat-treated for strength and toughness.

The thrust bearings are designed to sustain the weight on bit and bearing the downward hydraulic thrust load of the rotor.

The unique design of SDI's combination of PDC and standard roller thrust bearings enable the same set of bearings to carry the on-bottom as well as the off-bottom load. This important feature reduces the number of bearing races within the limited available space, reducing the bit to bend, and increasing the thrust load capacity and the life of the bearing pack.

The radial bearings rigidly support the bearing mandrel inside the bearing housing. They are designed to accept the radial forces generated during drilling, while keeping the bearing mandrel aligned and concentric with the axis of the bearing housing.

BIT BOX

The bit box is an integral part of the bearing mandrel. The outside diameter is sized to accept a specified box connection. While all external components of the motor are stationary relative to the drill string, the bit box is the only external component that has a rotary motion independent of the rotational speed of the drill string.

NEAR BIT STABILIZER

SDI motors are available with removable or integral stabilizers. The removable stabilizers are screwed on the bearing housing at our service facilities and configured to their specified torque values.

In the case clients wish to have the option of installing stabilizers on the motor at the rig site, the motor is shipped with a thread protector installed on the external threads of the bearing housing.

03 JOB PLANNING

When planning the job, it is essential to consider several factors in order to select the right motor for your specific application.

HOLE SIZE

The SDI drilling motor fleet was designed to support a wide range of hole sizes. The recommended hole size for each motor can be found in the Appendix section. We encourage consulting SDI personnel as any deviation could result in hole problems and/or cause premature motor failure.

REQUIRED DOGLEG SEVERITY

Refer to the Appendix for the predicted build rate for each size motor. The values listed in the Appendix should be used as a guideline only, since factors such as the bit type, formation characteristics, BHA configuration, Weight-On-Bit (WOB), rotary RPM, hole OD, etc., affect the actual build rate.

If the motor is intended for rotary drilling, refer to rotation limit plots in the Motor Specification section.

BIT SELECTION

The proper selection of the drill bit can substantially increase the penetration rate, reduce drilling cost, and improve motor performance.

The bit's Total Flow Area (TFA) affects both motor performance and the ability to clean the hole. An undersized bit TFA will result in high-pressure drop across the bit and lower than expected flow rate. Inadequate flow rate can result in overheating and damage to the bit, hole-cleaning problems, and will starve the motor of the adequate fluid needed to operate at its optimum performance. On the other hand, an oversized TFA might not provide the fluid momentum necessary to remove the cuttings properly. The formulas required to calculate the bit TFA are provided in the Appendix. The Motor Specification section of this handbook lists the recommended bit pressure drop for each size motor. If the flow requirements needed for your specific application exceed the maximum allowable motor flow rate, a bored rotor can be provided to supply the additional fluid for some power sections.

For angle building runs, the design of the bit's gauge and length becomes critical. High drag, Polycrystalline Diamond Compact (PDC) bits exert more stress on the motor components than traditional cone or less aggressive bits. Also, high RPM motors combined with high WOB require more flow to cool the bit. Contact the bit manufacturer for the minimum recommended bit flow rate and speed.

DRILLING FLUID

The most fluid-sensitive component of the SDI motor is its stator elastomer. Therefore, it is important that the type of mud and all of its characteristics are given to the SDI representative during pre-job planning. SDI's drilling motor fleet was designed to operate successfully with water-based mud, fresh water, brine, seawater, synthetic and oil-based mud. When drilling with an oil-based mud, the aniline point of the mud must exceed the downhole static temperature to maximize the stator lining life. The mud manufacturer will be able to provide the aniline point of the mud.

The pH level of the drilling fluid can affect the life of the drilling motor. The recommended pH level is between 4 and 10 for SDI motors.

If there is a prolonged interruption in drilling, periodic circulation through the motor will increase motor life, as the stagnation of fluid inside the motor will cause deterioration.

The solid content of the drilling fluid should be maintained below 5% and the sand content below 2%. Any deviation from the specified limits will cause the bearings and elastomer lining to wear rapidly, which will result in a gradual reduction in the output power of the motor.

Mud weight is another factor that should be considered when planning the drilling operation. Generally heavier mud (12 lb/gal [14.37 kg/m3] or greater) will wear the motor at a faster rate than lighter mud. When using heavy drilling fluid, keep the sand content below 0.5% to minimize a possible washing in the drilling motor.

Any additives to the mud system should be carefully selected to comply with these specifications.

If a substantial amount of gas or air is trapped in the drilling fluid, it should be removed to prevent any possible damage to the stator rubber.

Medium to fine lost-circulation material can be used, as long as they are mixed thoroughly. If the drilling conditions require the use of coarse material, we recommend the use of jet subs above the motor to bypass a portion of the particles and prevent plugging.

The use of solid additives with rough or sharp texture should be avoided, as they have the potential to scar or cut the stator rubber lining.

HOLE TEMPERATURE

Bottom hole static temperature affects the physical and mechanical properties of the stator's elastomer. Therefore, it is important that the expected temperature range is given to the SDI representative during pre-job planning. An increase in temperature decreases the mechanical strength of the stator's rubber lining and may cause temperature related swelling.

Excessive interference increases the frictional heat generation and will over-stress the rubber compound, resulting in premature stator failure.

SDI calculates the rotor/stator interference to provide the needed power in all sections of the well based on average expected downhole temperature. Figure 3 illustrates the reduction in the tensile strength of the stator elastomer lining as the temperature increases.

Any reduction in the differential pressure of the motor while drilling will significantly increase the life of the elastomer.

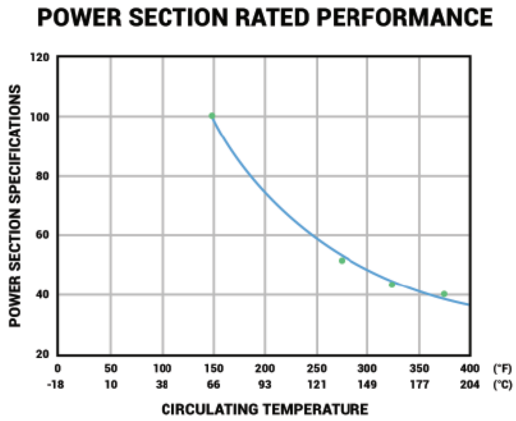


Figure 3. Temperature effects on Tensile strength

To increase the motor life, certain cautionary measures should be employed when drilling in a hot-hole environment. These measures are addressed in the Motor Operation section of the handbook.

ROTOR NOZZLE USAGE

With the exception of high-speed power sections (1:2 lobe ratio), most SDI rotors are bored to allow various size nozzles. Rotor nozzles are used to increase the flow rate at the bit by directing a portion of the fluid through the rotor. The use of a rotor nozzle is recommended when system hydraulics require a flow rate that exceeds the maximum allowable flow through the motor. Refer to the Appendix for proper sizing of the nozzle.

POWER REQUIREMENTS

When selecting a motor, pay close attention to its maximum power output. The motor should be powerful enough to deliver the required amount of torque, at the right RPM, to turn the drill bit in response to the application of various WOB.

Most SDI motors are available with hard rubber in all power sections, which can increase the Rate of Penetration (ROP), decrease stalling, and drill harsh formations with more ease than a standard motor power section.

AIR DRILLING

When drilling a well using air or foam, special consideration must be taken when selecting the power section. SDI's air motors are provided in a high torque, low speed power section minimize the severity of off-bottom runaway speed that may be encountered in air drilling operations. Refer to SDI's product specification sheets for more details.

SDI recommends a non-petroleum based lubricant to be injected into the dry air at surface in order to provide lubrication to the moving parts inside the motor. On dry air, this is a best practice to keep the stator cool. The lubricant should be at least 3% soap concentration.

SDI recommends high accuracy pressure gauges that indicate 25 psi (172 kPa) increments to be fitted to surface lines. When making connections, the pressure should be allowed to bleed off, and reduce the flow rate by half when starting a motor after connections.

04 MOTOR OPERATION

This section provides a general guideline regarding the use of SDI drilling motors.

SDI's drilling motors arrive at the rig site with all internal and external connections made-up to the specified torque. The near bit stabilizer, if requested, is installed and made-up to the full recommended torque value. The bit box and top sub connections, selected by the customer, are then fitted with thread protectors. Once the drill bit is installed, the motor is ready for operation.

SURFACE TESTING

Testing tools on surface prior to use is recommended to minimize the risk of operational issues once the tool is downhole. Surface motor tests should be conducted without the bit in order to avoid potential damage.

Recommended testing procedures:

1. Use correct lift sub at all times. Also, ensure lift sub and drilling motor connection is sound by testing with a chain tong. Lift motor with top drive or elevators and set in slips. Safety clamps and dog collars are recommended.
2. Connect the motor (to top drive or kelly) after removing the lift sub. Remove the dog collar/safety clamp, then raise the motor out of the slips.
3. The motor should be lowered until the bit box is just below the rotary table, with the bit box still in sight.
4. Gradually begin pumping, increase the flow rate until the bit box is turning.
5. There should be some leakage noted coming from above the bit box.
6. Gradually increase the flow rate to the minimum according to the motor specifications and record flow rate and pressure.
7. Turn flow off and check thrust bearing clearance by performing a squat thrust test. Reference Table 2 (below) for acceptable wear specifications.

Table 2
Allowable Thrust Bearing, Radial Bearing, and Coupling Wear of the Bit Box

Motor Size	Maximum Axial Play		Maximum Circumferential Play		Maximum Radial Play	
TiTAN22						
5.00"	0.100"	2.54 mm	N/A	N.A	0.043"	1.09 mm
5.15"	0.100"	2.54 mm	N/A	N/A	0.052"	1.32 mm
6.60"	0.100"	2.54 mm	N/A	N/A	0.052"	1.32 mm
7.15"	0.100"	2.54 mm	N/A	N/A	0.065"	1.65 mm
9.15"	0.130"	2.54 mm	N/A	N/A	0.065"	1.65 mm

INSPECTIONS BETWEEN RUNS

- Evaluate all stabilizers for wear and damage prior to attempting another run
- Turn flow off and check thrust bearing clearance by performing a squat thrust test. Reference table 2 for acceptable wear specifications
- Drain all drilling fluid from tool by rotating bit box clockwise
- Flush the tool with fresh water or non-petroleum oil if the tool will be laid down

TRIP IN GUIDELINES

- Minimize the amount of stationary assembly time
- Descend at a controlled rate
- Trip the drill string with the blocks unlocked
- Use caution when approaching BOP, liner hanger, casing shoe, bridges, known tight spots, ledges or bottom

- Slowly ream through tight spots with maximum recommended flow rate and string rotation of 30 RPM or less
- Circulate occasionally to both avoid plugging the nozzles of the bit and when temperatures are above 250°F (121°C) to cool the BHA
- PDC bits should not be circulated for extended periods of time without WOB to avoid bit damage
- If the float valve is not used and the drill string is empty, the annulus pressure combined with the dynamic pressure, generated while tripping in will force the drilling fluid through the bit and into the motor causing the motor to rotate in reverse. This could result in unscrewing or breaking one or more internal components. It is recommended to use at least one float, and if not feasible, keep the drill string full at all times and trip in slowly. SDI recommends filling the pipe every 500 ft
- Approximately 100 ft from bottom, start pumps and trip in at a controlled speed ensuring not to spud the motor

STAGING

Motor preparation procedures for High Temperature operations

1. Normal tripping in procedures should be practiced until arriving at a depth with a predicted temperature of 250°F (121°C) or greater.
2. Once the measured depth with the predicted temperature is reached, break circulation to cool the BHA
3. Circulate for approximately 5 min at every fill point
4. Once drilling operations have begun, gradually apply differential pressure to the recommended maximum reduced differential pressure
5. Refer to Power Section Rate of Performance chart

High Temperature Guidelines

High temperature wells are defined as wells with a downhole temperature above 250°F (121°C).

Motor Preparation Procedures in Cold Temperature Operations

1. It is critical to warm a motor prior to operations in cold temperatures.
2. Heat the entire motor, from the bit box end, using steam until it is warm to the touch.
3. Do not heat the motor rapidly or inconsistently to prevent internal component damage. A general practice is to heat over a 60 min period.

HOLE OD RESTRICTIONS

Use caution when motor with bent sub or non-zero angle housing travels through BOP, liner hanger, casing shoe, bridges, known tight spots, ledges or bottom

WASHING AND REAMING

Maintain flow rate above minimum requirements to clean and cool the motor bearings. It is recommended to flow as much as possible without exceeding maximum to easily identify stalls.

To avoid motor damage, limit reaming with minimal WOB, and maximum flow for which that power section has been rated.

While cleaning and backreaming, do not exceed the recommended speeds located on the rotational limit charts. Also, ensure you maintain flow rate and lower string rotation speed when working through a tight spot.

Do not backream with a motor under these circumstances:

- More than 90 ft (30 m) of backreaming

- Excessive tension on the motor while backreaming may cause damage to thrust bearings and mandrel wear
- It is not recommended to rotate the motor at greater RPM or through higher doglegs than what is specified on the rotational limit chart

DRILLING PROCEDURES

1. Gradually increase flow rate to the desired GPM (LPM) once the bit is 6-10 ft (2-3 m) off-bottom, while not exceeding the maximum flow rate of the power section. If available, it is recommended to set the automatic drilling system to slowly tag bottom. Once the bit is 1-2 ft off-bottom ensure the WOB and differential pressure is zeroed.
2. Monitor flow rate and pump pressure (side loads may affect calculated off-bottom pressure)
3. Perform drill-off test to determine ideal differential pressure and WOB

SLIDING

Prior to orienting for a slide, gradually work out any drillstring torque. Orient the tool face with the consideration of the BHA reactive torque and lock the rotary table or top drive. Use caution to avoid stacking weight, which can potentially release, causing damage to the motor and loss of tool face control.

ROTARY DRILLING

All motors can be used for rotary drilling operations, with the maximum possible string RPM dependent on the bend angle.

High drillstring RPM will cause excessive bit speeds and excessive wear to the BHA. Stick slip effects can cause instantaneous BHA rotation speeds up to three times the surface RPM resulting in severe damage to downhole tools. Higher rotary speeds may be necessary in some circumstances, but the life expectancy of the motor and other downhole equipment will be reduced.

ROTARY RPM

While rotating, a lateral force is exerted on the drill bit by the formation. The magnitude of the force is directly proportional to the bit to bend length, bend angle, dog leg severity, and formation hardness. The induced bending stress on the motor increases the risk of fatique failure. Reference rotational limit charts for string rotation speeds.

Note: When transitioning from sliding to rotating, pull back until the bit is above the slid interval. Then, using a maximum rotary RPM of 25, carefully ream back to bottom. Maintain this low RPM until the bit to bend length is drilled off.

STALLING

A stall occurs when the rotor stops rotating while the drilling fluid continues to flow through the motor. During a stall, the stator elastomer is pushed aside resulting in severe stresses within the elastomer and eventually fatigue failure of the stator as well as high stresses of the transmission and bearing section, which can result in catastrophic damage.

A short occurrence of the power section not supplying the needed torque for the bit to continue rotating is defined as a microstall, which in multiples is just as damaging as a hard stall. High WOB and rotating in large dog legs increases the chances of microstalling.

Note: Stalling during rotary drilling (over running the bit) is not as noticeable as stalling while sliding. Stalling while rotating causes more damage to the stator elastomer due to the rotor rotating in reverse while drilling fluid continues to flow through the power section.

If a stall is encountered on a Kelly drive:

1. Stop rotation immediately.
2. Reduce flow rate by at least 50%.
3. Use rotary table brake to gradually release stored torque.
4. Pick off bottom slowly.
5. Stage pumps back to normal operating flow rates and pressure. Monitor pressure and slowly resume drilling operations. If abnormal pressures continue, or unable to drill consult Onsite Drilling Manager and SDI personnel for confirmation to trip out. Refer to the rotor catch tripping instructions if excessive pressures are encountered.

If a stall is encountered on a Top drive:

1. Stop rotation immediately.
2. Reduce flow rate by at least 50%.
3. Lock brake on the top drive, gently hoist to string weight, and slowly release the brake on the top drive to release the trapped torque. The lower string weight will greatly reduce the trapped torque, which will lessen the backlash/whip.
4. Pick bit off-bottom slowly.
5. Stage pumps back to normal operating flow rates and pressure. Monitor pressure and slowly resume drilling operations. If abnormal pressures continue, or unable to drill consult Onsite Drilling Manager and Directional Coordinator for confirmation to trip out. Refer to the rotor catch tripping instructions.

PRESSURE DROP

Do not exceed maximum recommended differential pressure or circulation rates, as this will reduce the life of the stator elastomer and bearing assembly. Refer to Motor Specification section for maximums.

INCIDENT ASSESSMENT ACTIONS

The following is a list of the most commonly observed motor difficulties:

Sudden Pressure Increase

- Stalled motor
- Bit or tool plugged
- Seized bearing assembly
- Suspected rotor catch engagement

Low/No Penetration

- Worn bit
- Formation change
- Stabilizer hang up
- Damaged or worn stator elastomer

Slow Pressure Decrease

- Drill string or dump sub washout
- Lost circulation
- Well control issue

Sudden Pressure Decrease

- Back-off in the drill string or on the motor
- Fracture of the driveshaft assembly

Bit Box Does Not Spin While Circulating

- Backed-off connection
- Fracture of the driveshaft assembly
- Severe lost circulation

Bit Box Does Not Spin, Minimal Flow When Circulating

- Seized bearing assembly
- Chunked stator elastomer
- Partial plugging within the drillstring

VIBRATION

Vibration can cause the most significant motor fatigue and should be mitigated in order to avoid downhole failures.

These are the 3 types of drilling vibration:

- Torsional Vibration (Stick Slip)
- Lateral Vibration
- Axial Vibration

Reference Shock and Vibration Limitations section in the Appendix for more information.

TORSIONAL VIBRATION

Torsional vibration can be attributed to alternating speeding up and slowing down of the BHA while rotating, as the bit/formation interaction may cause the bit to stop momentarily. When the bit instantaneously stops, the drill string continues turning with increased torque, which then frees the bit to accelerate (otherwise known as bit whirl). BHA induced stick slip, which occurs when contact points become stuck, can have a similar effect. This can cause connections to back off or damage to all BHA components.

Symptoms

- Large and erratic surface RPM and torque fluctuations, especially noticeable on a top drive
- Fluctuating sound from top drive or kelly
- Cutter/insert damage; bit/stabilizers wearing under-gauge
- Poor hole cleaning, under-gauge or washed out hole
- Shock/vibration measurements received from MWD
- Connection fatigue cracks; fractures of BHA components; connection back-off
- Fractured or cracked motor drive line components such as bearing mandrels or transmissions
- Erratic increase and decrease in surface torque.
- Top drive stalling
- Increase in lateral vibrations
- Housing or connection fracture
- Chipped cutters/excessive bit wear

Solutions

- Improve the lubrication qualities of the drilling fluid
- Adjust operating parameters (i.e. increase RPM or decrease WOB
- Pick up off-bottom and work out all drillstring torque
- Drill with less aggressive PDC bit
- Use alternative BHA components or placement

LATERAL VIBRATION (BIT/BHA WHIRL)

Lateral vibration occurs when the BHA comes into contact with the side of the wellbore. This causes drilling inefficiencies, as well as damage to BHA components.

Causes

- Harmonic resonance of drill string
- Excessive RPM and stick slip
- Low WOB with High RPM
- Lack of lubrication in mud
- Reaming/backreaming, hole opening, or drilling out of casing

Symptoms

- Poor penetration rates and higher Mechanical Specific Energy (MSE) than expected from that formation
- Damage to the bit is probably in the shoulder or randomly scattered across the body. Dull characteristics will be chipped and broken or missing cutters
- Rotary torque fluctuations

Solutions

- Pick up off-bottom and hold string stationary until all energy is released (typically a couple minutes)
- Increase WOB, reduce RPM and try to confirm with downhole measurements while drilling
- Improve the lubrication qualities of the drilling fluid

DETECTING LATERAL VIBRATIONS

- Erratic fluctuations in surface torque created by severe stick slip usually accompanies high lateral shocks
- Slower ROP

MITIGATING LATERAL VIBRATIONS

- Pick up off-bottom to work out all torque and vibration
- Change RPM or change WOB
- Modify BHA (i.e., add stabilizer)

AXIAL VIBRATION

Axial vibration, also known as “bit bounce,” is caused by a cyclical loading and unloading of the bit and the BHA in the axial direction. It is characterized by rapid cyclical movement of the neutral point in the BHA that causes the WOB to quickly increase and decrease.

Causes

- Excessive RPM
- Excessive WOB with high RPM
- Erratic fluctuations of the WOB/hook load
- Visible bouncing motion of the top drive and kelly hose
- Slower Rate of Penetration (ROP)
- Excessive damage/wear to bit

Symptoms

- Large WOB fluctuations (shaking hoisting equipment)
- Damage to the bit, broken cutters on cones, particularly the outer rows
- Internal inspection of bearings may find excessive wear
- High downhole vibration as recorded by MWD/LWD tool

Solutions

- Change RPM and WOB combinations to get a stable drilling situation and the MWD axial sensor will inform the directional driller that the vibration has been eliminated
- Pick up off-bottom/work out all torque
- Decrease RPM or WOB

ROTOR CATCH FUNCTIONING

The rotor catch is designed to mitigate losing a portion of the motor in the event of a housing connection failure.

If a connection back-off occurs, it must be identified quickly. Features for identification:

- Pressure loss when the bit is on-bottom (due to loss of flow through housing)
- When the motor is off-bottom the standpipe pressure will increase

- With WOB reapplied, the pressure increase disappears
- BHA should not be rotated if possible
- Circulation should be kept to a minimum
- SDI's directional personnel should be present during trip out

TRIP OUT PROCEDURE

Drilling fluid will typically drain from the lower end of the bearing assembly while the motor is tripping out of hole. When tripping through high-angle curves, ensure tool face is highside. Avoid rotating drill string, which can cause damage and wear to the bit and motor.

LAY-DOWN PROCEDURES

SURFACE CHECKS BEFORE LAY-DOWN

1. Surface check inspection procedures should be repeated with attention paid to the functionality; bit box rotation, fluid bypass rate above the bit box, and axial and radial movement of the bottom end of the drilling motor.
2. A mud lubricated drilling motor lay-down review should be performed if the drilling motor is going to be rerun.
3. Review takes into account extreme drilling conditions and allows reuse of drilling motor based on mandatory limits, in combination with the operator's judgement.
4. Drain the motor by rotating the bit box.

GENERAL PRACTICE

It is important to flush the drilling motor with fresh water or non-hydrocarbon oil before laying it down. Failure to do so will allow the drilling fluid to further deteriorate components long after the drilling motor has been operated.

05 MOTOR SPECIFICATIONS

This section of the handbook provides critical information regarding the physical characteristics and performance parameters of SDI's drilling motors. They are classified as Standard, Performance and Air motors.

SDI is committed to ongoing improvements of drilling motors and procedures. As a result, the information in this handbook is subject to change without notice.

The flow rate, RPM, torque, and differential pressure correlation is presented graphically for each motor. The proper interpretation of these graphs is crucial in maintaining the specified operating limits of the motor.

HOW TO INTERPRET THE GRAPHS

Figure 1 on page 32 shows a typical graph used to determine the performance of a specific motor. Using this graph, the RPM and the output torque of the motor can be determined at a certain differential pressure.

To determine the approximate motor RPM, follow this procedure:

1. Locate the desired differential pressure on the corresponding axis.
2. From this point, draw a vertical line until it intersects the RPM curve at the desired gal/min (L/min).
3. From the point of intersection, draw a line perpendicular to the RPM axis to find the corresponding bit rotary speed. For example: a 6½" SDI motor with a 7/8 lobe ratio and 5.0 stages operating at 400 psi (2,758 kPa) of differential pressure and 600 gal/min (2,271 L/min) is about 174 RPM.
4. The RPM graph can be extrapolated to reflect the flow rates not shown on the graph. For instance,

to determine the RPM of the motor at 525 gal/min (1.987 L/min), draw a curve, parallel to the other curves, in the mid-point between the 600 gal/min (2,271 L/min) and 450 gal/min (1,703 L/min). Use this curve to determine the motor RPM at 525 gal/min (1,987 L/min) and a certain differential pressure.

To determine the output torque of a certain motor, follow these steps:

1. Locate the desired differential pressure on the corresponding axis and draw a perpendicular line until it intersects the torque line.
2. From the point of intersection, draw a line perpendicular to the torque axis to find the corresponding output torque. For example, a 6½" SDI motor with a 7/8 lobe ratio and 5.0 stages operating at 400 psi (2,758 kPa) of differential pressure has an output torque of about 3,720 ft-lb (5,044 Nm).

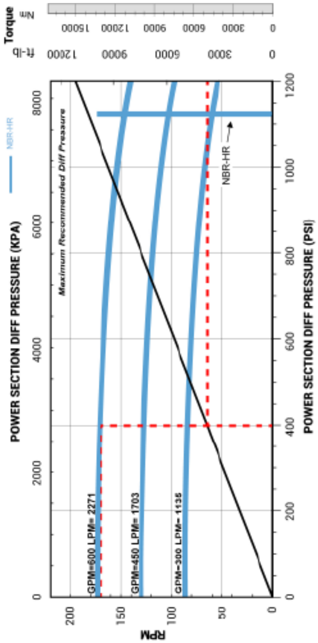
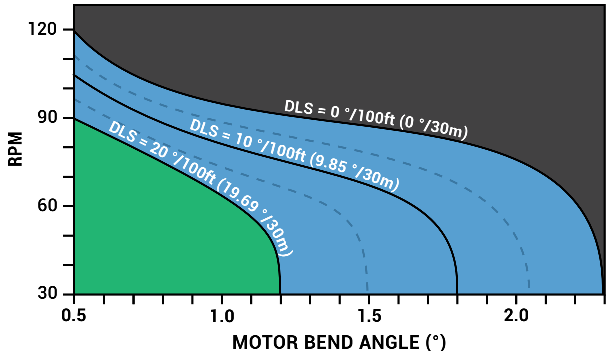


Figure 1: Performance Graph

HOW TO USE ROTATION LIMIT PLOTS

1. Determine the wellbore curvature (DLS) that the motor is currently in.
2. Draw a vertical line from the motor bend angle value on the x-axis upwards to the appropriate DLS curve (DLS, between curves provided, should be estimated by splitting the difference between two previously drawn curves).
3. Draw a horizontal line from the point where the vertical line (step 2) intersects with the DLS curve, to the corresponding RPM value (y-axis) in that scenario.



EXAMPLES:

1. **Basic Chart Use** - A 5°/100 ft curve has been drilled with a 1.75° Motor Bend. You would then, reasonably be able to rotate at 70 RPM within at that curvature. Once you've drilled away from the base of the curve, and the bend is now in a straight and enlarged hole, the effective DLS is now 0°/100 ft and the new allowable RPM is around 84 (Refer to red dashed lines in Figure 1).

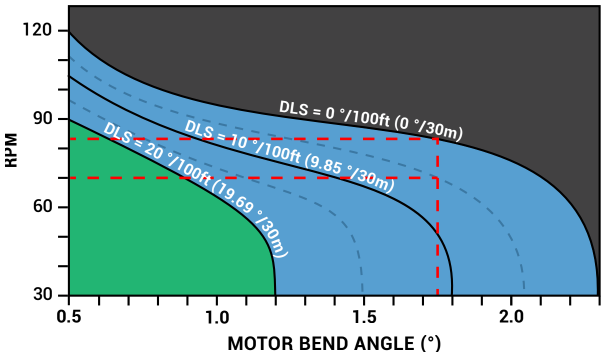


Figure 1: Illustration of Example 1

2. **Adding a DLS Curve** - A hypothetical, 8 °/100 ft, curve is drilled entirely while sliding, with a 1.9° bend in the motor. First, a DLS curve for 8°/100ft must be drawn on the figure. Understanding that 7.5°/100 ft DLS curve would be in the middle between the 5°/100 ft dashed curve and the 10°/100 ft solid curve, an 8°/100 ft curve can be placed slightly to the left of where the 7.5°/100 ft curve would go (refer to red dashed curve in Figure 2). Once the DLS curve is determined, the same procedure that was used in Example 1 can be followed to determine the RPM limits.

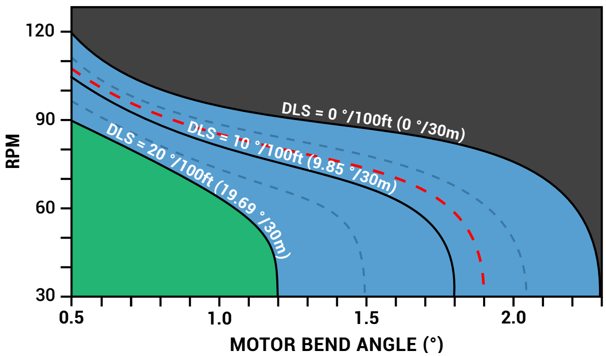


Figure 2: Illustration of Example 2

3. **"Out of Spec" Rotation** - Ex: a 20°/100ft is drilled with a 2.3° motor bend. According to the chart, rotating once you've landed this curve would be "out of spec". In this scenario, a low RPM (maximum of 30) would have to be used until the bend is effectively out of the curve and in a straight wellbore. Once in a straight wellbore, RPMs can be increased to 50 (refer to red dashed line in Figure 3).

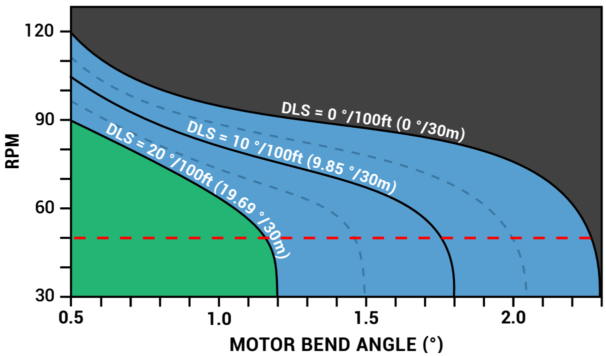


Figure 3: Illustration of Example 3

*Chart data is based on bending-moment limitations of the bent housing. The primary criteria used to establish these limit lines is the bending moment that results in the onset of shoulder separation at the bend. The plot is representative of a sustainable operation in a specific wellbore curvature (DLS). The chart only applies to slick motors and does not, in any way, attempt to predict build/drop tendencies of the BHA. DLS lines correspond to the wellbore curvature that the motor is currently in. If a particular bend assembly is in a curve that, according to the chart, prevents rotation, then slowly rotate (30 RPM) until the motor has effectively drilled itself out of the curve. Prolonged rotation in a curve (>10 minutes) or sustained rotation rates above 30 RPM will accelerate fatigue in the motor and are considered out-of-spec operations. Configurations with stabilizers and special equipment need to be looked at on an individual basis.

MOTOR SPECIFICATIONS SUMMARY TABLE

Motor Name		TiTAN22				
Motor Size (OD)	inch	5.00	5.00	5.00	5.15	5.15
	mm	127	127	127	131	131
Lobe	config	7/8	7/8	7/8	6/7	6/7
Stages	num	3.1	3.8	5.0	6.6	8.0
Length	ft	30.9	27	27.9	36.1	32.8
	m	9.41	8.22	8.50	11.01	9.99
Recommended Hole Sizes	in	6-6¼	6-6¼	6-6¼	6-6¼	6-6¼
	mm	152-159	152-159	152-159	152-159	152-159
Max Bend Angle	deg	2.38°	2.38°	2.38°	2.38°	2.38°
Bit to Bend Length	in	40.6	40.6	40.6	45	45
	m	1.03	1.03	1.03	1.14	1.14
Bit Box Connection	API Reg Box	3½	3½	3½	3½	3½
Max WOB	lbs	30,000	30,000	30,000	30,000	30,000
	DaN	13,345	13,345	13,345	13,345	13,345
Max Overpull for Rerun	lbs	60,000	60,000	60,000	60,000	60,000
	DaN	26,689	26,689	26,689	26,689	26,689
Overpull to Yield Motor	lbs	120,000	120,000	120,000	120,000	120,000
	DaN	53,379	53,379	53,379	53,379	53,379
Max Bit Pressure Drop	psi	750	750	750	750	750
	kPa	5,171	5,171	5,171	5,171	5,171
Opt Bit Pressure Drop	psi	100-600	100-600	100-600	100-600	100-600
	kPa	690-4,136	690-4,136	690-4,136	690-4,136	690-4,136
LCM Capability	nut plug	40 lb	40 lb	40 lb	40 lb	40 lb
Max Differential Pressure	psi	700	900	1,180	1,560	1,880
	kPa	4,810	6,200	8,200	10,700	13,000
Stall Differential Pressure	psi	1,050	1,410	1,860	2,450	2,970
	kPa	7,210	9,700	12,800	16,900	20,500
Torque at Max Diff Pressure	ft-lbs	5,460	4,130	4,670	8,550	6,110
	Nm	7,402	5,600	6,400	11,592	8,300
Stall Torque	ft-lbs	8,190	6,500	7,350	13,460	9,630
	Nm	11,104	8,900	10,000	18,249	13,100
Flow Range	gal/min	150-275	100-250	150-300	200-425	150-330
	L/min	570-1,041	380-950	570-1,140	760-1,608	570-1,320
Speed Range	RPM	47-95	50-140	90-190	90-180	120-280
Speed Ratio	rev/gal	0.32	0.54	0.62	0.46	0.79
	rev/L	0.08	0.14	0.16	0.12	0.20
Torque Slope	ft-lb/psi	7.83	4.62	3.97	5.51	3.25
	Nm/kPa	1.54	0.91	0.78	1.08	0.64

MOTOR SPECIFICATIONS SUMMARY TABLE

Motor Name		TiTAN22				
Motor Size (OD)	inch	5.15	6.60	6.60	6.60	6.60
	mm	131	168	168	168	168
Lobe	config	6/7	4/5	5/6	7/8	7/8
Stages	num	10.4	7.0	8.3	3.3	5.0
Length	ft	36.5	30.9	38.3	33.8	29.6
	m	11.14	9.41	11.67	10.3	9.02
Recommended Hole Sizes	in	6-6¼	7⅞-8¾	7⅞-8¾	7⅞-8¾	7⅞-8¾
	mm	152-159	200-222	200-222	200-222	200-222
Max Bend Angle	deg	2.38°	2.38°	2.38°	2.38°	2.38°
Bit to Bend Length	in	45	49	49	49	49
	m	1.14	1.2	1.2	1.2	1.2
Bit Box Connection	API Reg Box	3½	4½	4½	4½	4½
Max WOB	lbs	30,000	60,000	60,000	60,000	60,000
	DaN	13,345	26,689	26,689	26,689	26,689
Max Overpull for Rerun	lbs	60,000	105,000	105,000	105,000	105,000
	DaN	26,689	46,706	46,706	46,706	46,706
Overpull to Yield Motor	lbs	120,000	210,000	210,000	210,000	210,000
	DaN	53,379	93,413	93,413	93,413	93,413
Max Bit Pressure Drop	psi	750	1,000	1,000	1,000	1,000
	kPa	5,171	6,894	6,894	6,894	6,894
Opt Bit Pressure Drop	psi	100-600	100-750	100-750	100-750	100-750
	kPa	690-4,136	690-5,171	690-5,171	690-4,136	690-5,171
LCM Capability	nut plug	40 lb	40 lb	40 lb	40 lb	40 lb
Max Differential Pressure	psi	2,340	1,580	1,960	780	1,180
	kPa	16,130	10,894	13,500	5.400	8,200
Stall Differential Pressure	psi	3,510	2,360	3,080	1,230	1,860
	kPa	24,200	16,272	21,200	8,500	12,800
Torque at Max Diff Pressure	ft-lbs	8,610	9,090	13,030	13,150	10,650
	Nm	11,673	12,324	17,700	17,900	14,500
Stall Torque	ft-lbs	12,920	13,630	20,530	20,710	16,770
	Nm	17,517	18,480	27,900	28,100	22,800
Flow Range	gal/min	225-425	300-600	350-750	300-600	300-650
	L/min	852-1,608	1,140-2,270	1,320-2,840	1,140-2,270	1,140-2,460
Speed Range	RPM	157-300	149-298	130-290	50-90	80-188
Speed Ratio	rev/gal	0.70	0.49	0.38	0.15	0.29
	rev/L	0.19	0.13	0.10	0.04	0.08
Torque Slope	ft-lb/psi	3.68	5.77	6.68	16.95	9.06
	Nm/kPa	0.72	1.13	1.31	3.33	1.78

MOTOR SPECIFICATIONS SUMMARY TABLE

Motor Name		TiTAN22				
Motor Size (OD)	inch	6.60	7.15	7.15	7.15	7.15
	mm	168	181	181	181	181
Lobe	config	7/8	5/6	5/6	6/7	7/8
Stages	num	6.4	8.3	11.2	7.1	9.4
Length	ft	33.8	39.2	42.5	42.5	42.5
	m	10.3	11.94	12.95	12.95	12.95
Recommended Hole Sizes	in	7⅞-8¾	8½-9⅞	8½-9⅞	8½-9⅞	8½-9⅞
	mm	200-222	216-251	216-251	216-251	216-251
Max Bend Angle	deg	2.38°	2.12	2.12	2.12	2.12
Bit to Bend Length	in	49	57	57	57	57
	m	1.2	1.44	1.44	1.44	1.44
Bit Box Connection	API Reg Box	4½	4½	4½	4½	4½
Max WOB	lbs	60,000	60,000	60,000	60,000	60,000
	DaN	26,689	26,689	26,689	26,689	26,689
Max Overpull for Rerun	lbs	105,000	110,000	110,000	110,000	110,000
	DaN	46,706	48,930	48,930	48,930	48,930
Overpull to Yield Motor	lbs	210,000	240,000	240,000	240,000	240,000
	DaN	93,413	106,757	106,757	106,757	106,757
Max Bit Pressure Drop	psi	1,000	1,000	1,000	1,000	1,000
	kPa	6,894	6,894	6,894	6,894	6,894
Opt Bit Pressure Drop	psi	100-750	100-750	100-750	100-750	100-750
	kPa	690-5,171	690-5,171	690-5,171	690-5,171	690-5,171
LCM Capability	nut plug	40 lb	40 lb	40 lb	40 lb	40 lb
Max Differential Pressure	psi	1,510	1,960	2,520	1,670	2,120
	kPa	10,400	13,500	17,374	11,600	14,580
Stall Differential Pressure	psi	2,370	3,080	3,780	2,630	3,170
	kPa	16,400	21,200	26,062	18,200	21,870
Torque at Max Diff Pressure	ft-lbs	13,630	13,030	16,420	18,230	18,680
	Nm	18,500	17,700	22,260	24,800	25,330
Stall Torque	ft-lbs	21,470	20,530	24,630	28,700	28,020
	Nm	29,100	27,900	33,390	39,000	37,990
Flow Range	gal/min	300-650	350-750	450-750	500-750	500-750
	L/min	1,140-2,460	1,320-2,840	1,890-2,840	1,890-2,840	1,890-2,840
Speed Range	RPM	80-188	130-290	180-300	80-170	144-216
Speed Ratio	rev/gal	0.29	0.38	0.40	0.23	0.28
	rev/L	0.08	0.10	0.11	0.06	0.08
Torque Slope	ft-lb/psi	9.06	6.68	6.51	10.92	8.33
	Nm/kPa	1.78	1.31	1.28	2.15	1.73

MOTOR SPECIFICATIONS SUMMARY TABLE

Motor Name		TiTAN22			
Motor Size (OD)	inch	9.15	9.15	9.15	9.15
	mm	232.4	232.4	232.4	232.4
Lobe	config	7/8	7/8	7/8	7/8
Stages	num	4.0	5.7	5.9	7.0
Length	ft	32	38.34	44.4	44.4
	m	9.75	11.68	13.53	13.53
Recommended Hole Sizes	in	12¼-26	12¼-26	12¼-26	12¼-26
	mm	311-660	311-660	311-660	311-660
Max Bend Angle	deg	1.83°	1.83°	1.83°	1.83°
Bit to Bend Length	in	66	66	66	66
	m	1.67	1.67	1.67	1.67
Bit Box Connection	API Reg Box	6⅝-7⅝	6⅝-7⅝	6⅝-7⅝	6⅝-7⅝
Max WOB	lbs	120,000	120,000	120,000	120,000
	DaN	53,378	53,378	53,378	53,378
Max Overpull for Rerun	lbs	100,000	100,000	100,000	100,000
	DaN	44,482	44,482	44,482	44,482
Overpull to Yield Motor	lbs	250,000	250,000	250,000	250,000
	DaN	111,205	111,205	111,205	111,205
Max Bit Pressure Drop	psi	1,000	1,000	1,000	1,000
	kPa	6,894	6,894	6,894	6,894
Opt Bit Pressure Drop	psi	250-990	250-990	250-990	250-990
	kPa	1,723-6,205	1,723-6,205	1,723-6,205	1,723-6,205
LCM Capability	nut plug	40 lb	40 lb	40 lb	40 lb
Max Differential Pressure	psi	940	1,340	1,390	1,650
	kPa	6,500	9,300	9,600	11,376
Stall Differential Pressure	psi	1,490	2,110	2,190	2,600
	kPa	10,200	14,600	15,100	17,926
Torque at Max Diff Pressure	ft-lbs	14,830	25,920	21,870	25,210
	Nm	20,100	35,200	29,700	34,180
Stall Torque	ft-lbs	23,350	40,830	34,440	39,700
	Nm	31,700	55,400	46,700	53,826
Flow Range	gal/min	400-900	600-1200	400-900	400-1000
	L/min	1,510-3,410	2,270-4,540	1,510-3,410	1,514-3,785
Speed Range	RPM	60-140	80-150	60-140	60-160
Speed Ratio	rev/gal	0.15	0.12	0.15	0.15
	rev/L	0.04	0.03	0.04	0.04
Torque Slope	ft-lb/psi	15.77	19.35	15.77	15.32
	Nm/kPa	3.10	3.81	3.10	3.01

MOTOR SPECIFICATIONS
&
PERFORMANCE GRAPHS

TiTAN22 | PERFORMANCE DRILLING MOTOR

Scientific Drilling's TiTAN22 performance drilling motor is designed for the most extreme drilling environments in the industry. It has been engineered to run with the highest torque power sections, delivering ultimate reliability and durability in all sections of the well.

The TiTAN22 also features a unique Ti-Flex™ Titanium Flex Shaft and bearing pack assembly to deliver optimal performance in a wide range of applications.

DELIVERING THE ULTIMATE VALUE

- Enhanced WOB capacity, supporting increased and consistent ROP for superior drilling performance
- Rugged driveline design for ultra-high power torque sections, delivering maximized reliability
- Full rotational capabilities in all sections of the well, ensuring optimal wellbore integrity
- Innovative Ti-Flex™ Titanium Flex Shaft and bearing assembly for increased durability and extended tool life

TARGET APPLICATIONS

- Performance Drilling
- Extended Reach Laterals
- Factory Drilling in Shale Reservoirs
- One Run Applications
- Laminated Formations

TOOL RENDERING

TiTAN22 | PERFORMANCE DRILLING MOTOR

TiTAN22 | 5.00" 7/8 3.1

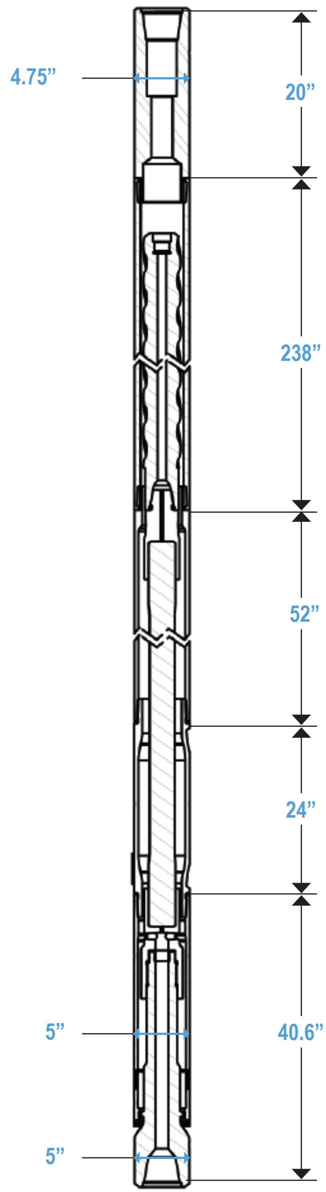
GENERAL SPECIFICATIONS	
OD	5.00 in (127 mm)
Length	30.9 ft (9.42 m)
Recommended Hole Sizes	6 - 6 1/4 in (152 - 159 mm)
Max Bend Angle	2.38°

BEARING SECTION	
Bit to Bend Length	40.6 in (1.031 m)
Bit Box Connection	3½ API Reg.
Max WOB	30,000 lbs (13,345 DaN)
Max Overpull for Rerun	60,000 lbs (26,689 DaN)
Overpull to Yield Motor	120,000 lbs (53,379 DaN)
Max Bit Pressure Drop	750 psi (5,171 kPa)
Opt Bit Pressure Drop	100 - 600 psi (690 - 4,136 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	7/8
Stages	3.1
Max Differential Pressure	700 psi (4,810 kPa)
Stall Differential Pressure	1,050 psi (7,210 kPa)
Torque at Max Diff Pressure	5,460 ft-lbs (7,402 Nm)
Stall Torque	8,190 ft-lbs (11,104 Nm)
Flow Range	150 - 275 gal/min (570 - 1,041 L/min)
Speed Range	47 - 95 RPM
Speed Ratio	0.32 rev/gal (0.08 rev/L)
Torque Slope	7.83 ft-lb/psi (1.54 Nm/kPa)

GENERAL DIMENSIONS

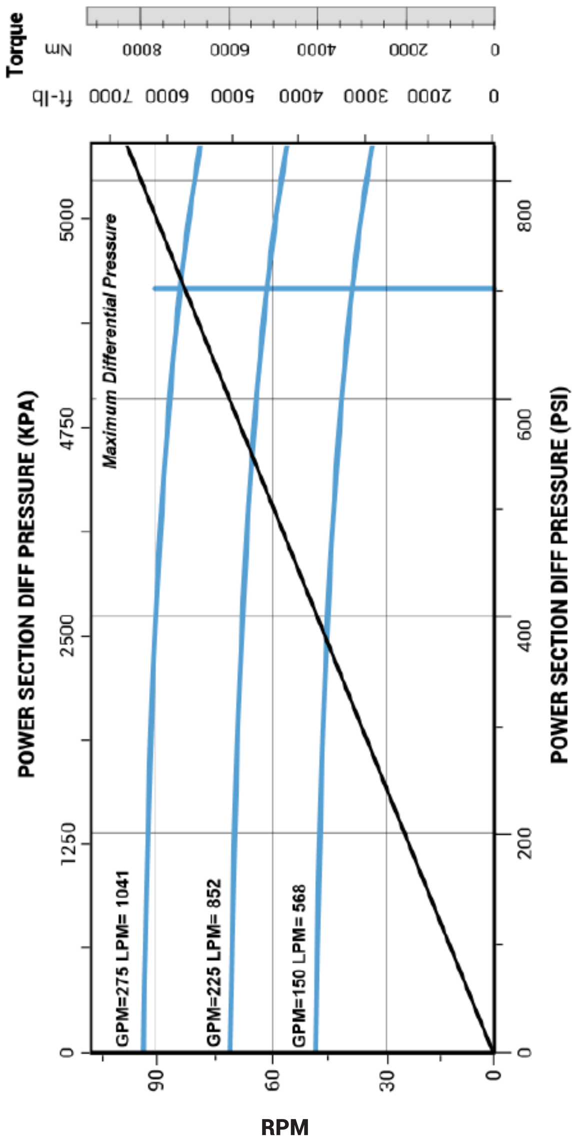
TiTAN22 | 5.00" 7/8 3.1



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 5.00" 7/8 3.1



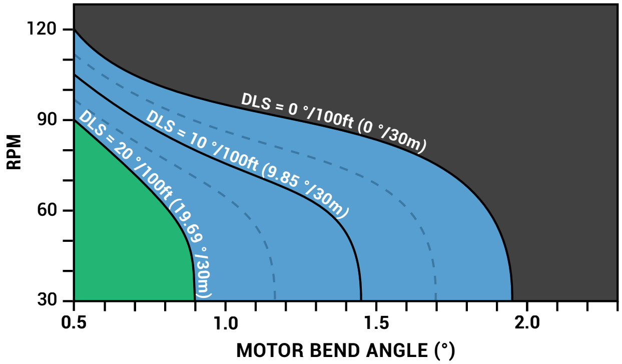
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

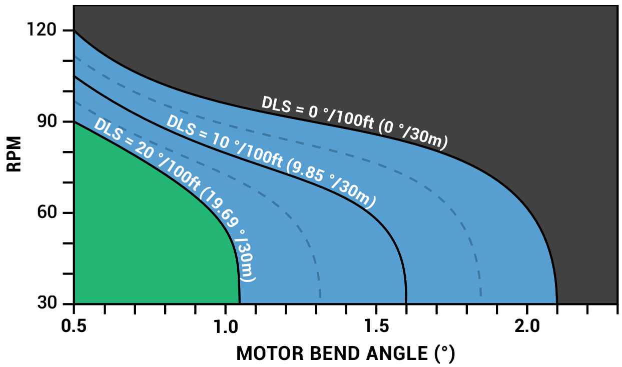
ROTATIONAL LIMIT

TiTAN22 | 5.00"

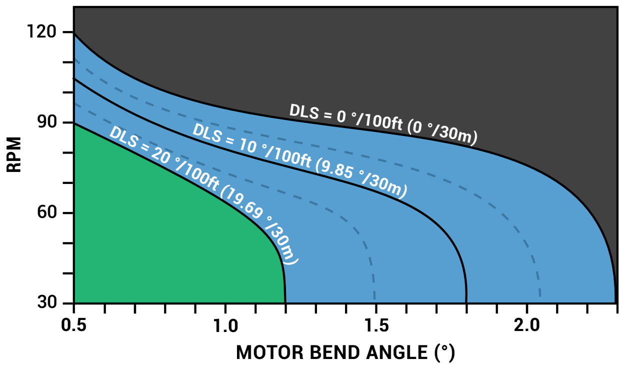
6" WELLBORE



6 ⅛" WELLBORE



6 ¼" WELLBORE



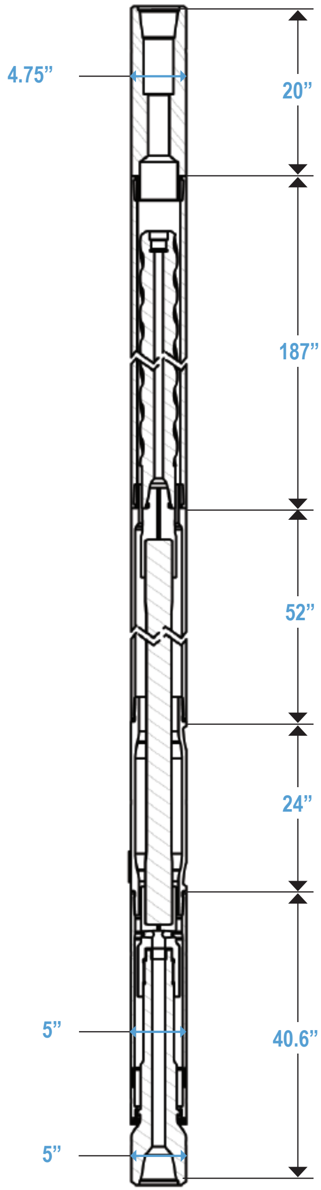
Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 5.00" 7/8 3.8

GENERAL SPECIFICATIONS	
OD	5.00 in (127 mm)
Length	27 ft (8.22 m)
Recommended Hole Sizes	6 - 6 ¼ in (152 - 159 mm)
Max Bend Angle	2.38°
BEARING SECTION	
Bit to Bend Length	40.6 in (1.031 m)
Bit Box Connection	3½ API Reg.
Max WOB	30,000 lbs (13,345 DaN)
Max Overpull for Rerun	60,000 lbs (26,689 DaN)
Overpull to Yield Motor	120,000 lbs (53,379 DaN)
Max Bit Pressure Drop	750 psi (5,171 kPa)
Opt Bit Pressure Drop	100 - 600 psi (690 - 4,136 kPa)
LCM Capability	40 lb nut plug
POWER SECTION	
Lobe Configuration	7/8
Stages	3.8
Max Differential Pressure	900 psi (6,200 kPa)
Stall Differential Pressure	1,410 psi (9,700 kPa)
Torque at Max Diff Pressure	4,130 ft-lbs (5,600 Nm)
Stall Torque	6,500 ft-lbs (8,900 Nm)
Flow Range	100 - 250 gal/min (380 - 950 L/min)
Speed Range	50 - 140 RPM
Speed Ratio	0.54 rev/gal (0.14 rev/L)
Torque Slope	4.62 ft-lb/psi (0.91 Nm/kPa)

GENERAL DIMENSIONS

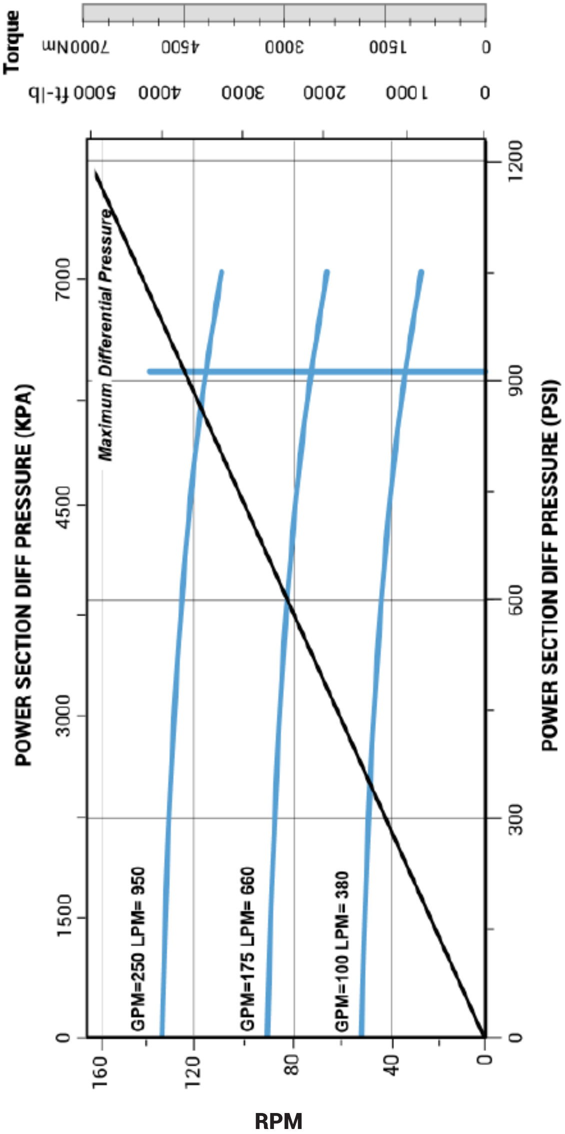
TiTAN22 | 5.00" 7/8 3.8



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 5.00" 7/8 3.8



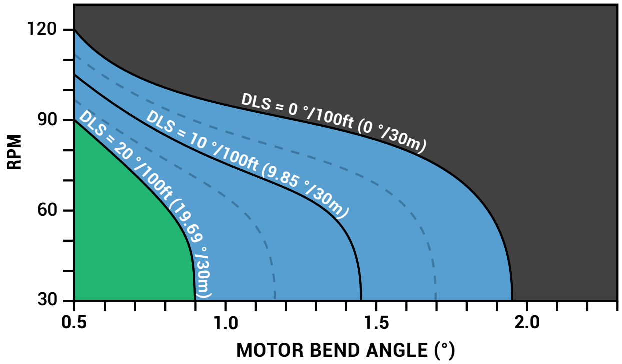
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

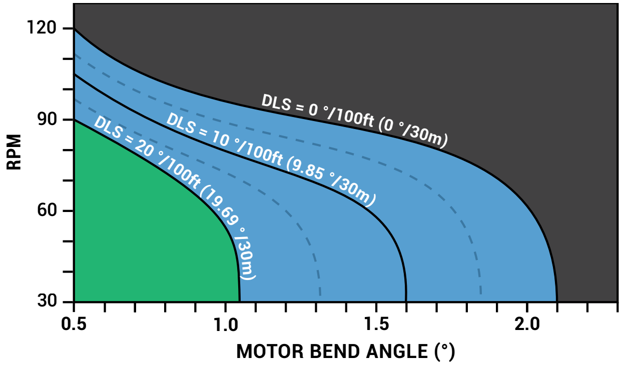
ROTATIONAL LIMIT

TiTAN22 | 5.00"

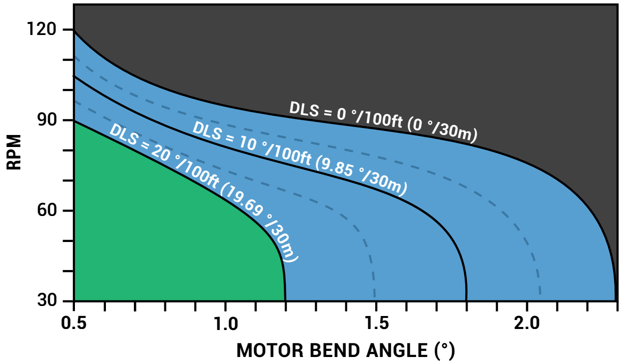
6" WELLBORE



6 ⅛" WELLBORE



6 ¼" WELLBORE



Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 5.00" 7/8 5.0

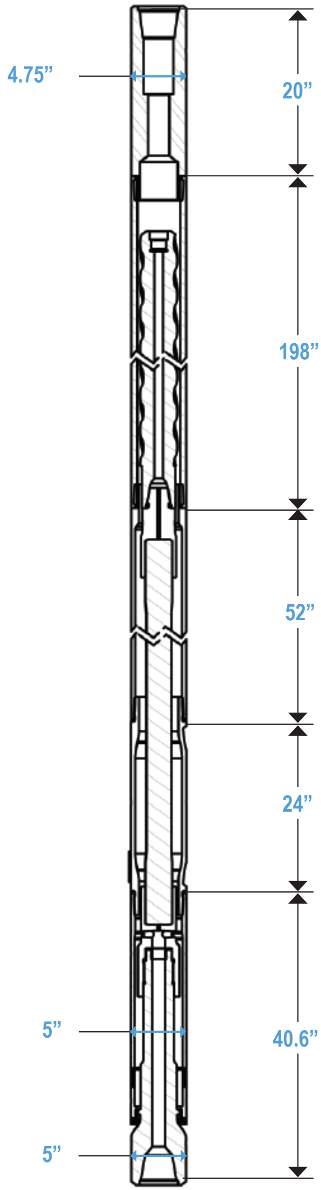
GENERAL SPECIFICATIONS	
OD	5.00 in (127 mm)
Length	27.9 ft (8.50 m)
Recommended Hole Sizes	6 - 6 ¼ in (152 - 159 mm)
Max Bend Angle	2.38°

BEARING SECTION	
Bit to Bend Length	40.6 in (1.031 m)
Bit Box Connection	3½ API Reg.
Max WOB	30,000 lbs (13,345 DaN)
Max Overpull for Rerun	60,000 lbs (26,689 DaN)
Overpull to Yield Motor	120,000 lbs (53,379 DaN)
Max Bit Pressure Drop	750 psi (5,171 kPa)
Opt Bit Pressure Drop	100 - 600 psi (690 - 4,136 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	7/8
Stages	5.0
Max Differential Pressure	1,180 psi (8,200 kPa)
Stall Differential Pressure	1,860 psi (11,800 kPa)
Torque at Max Diff Pressure	4,670 ft-lbs (6,400 Nm)
Stall Torque	7,350 ft-lbs (10,000 Nm)
Flow Range	150 - 300 gal/min (570 - 1,140 L/min)
Speed Range	90 - 190 RPM
Speed Ratio	0.62 rev/gal (0.16 rev/L)
Torque Slope	3.97 ft-lb/psi (0.78 Nm/kPa)

GENERAL DIMENSIONS

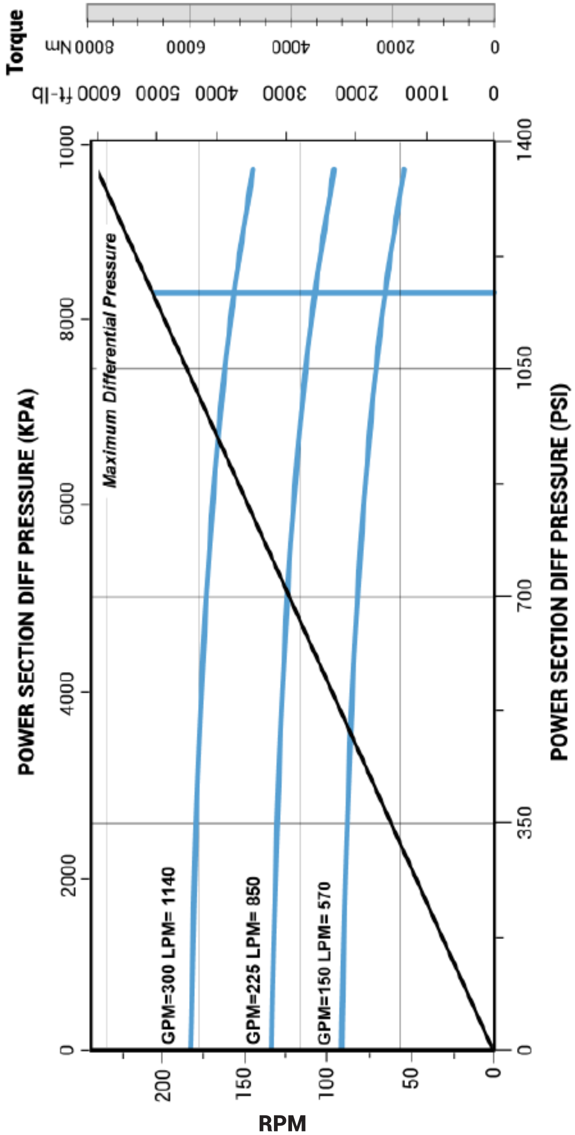
TiTAN22 | 5.00" 7/8 5.0



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 5.00" 7/8 5.0



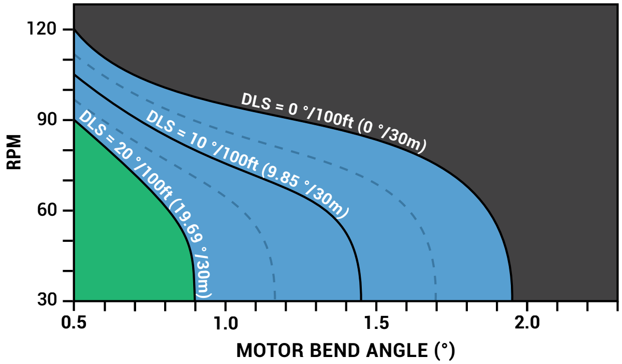
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

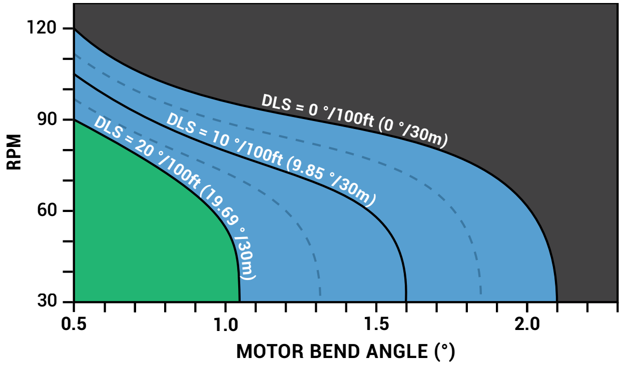
ROTATIONAL LIMIT

TiTAN22 | 5.00"

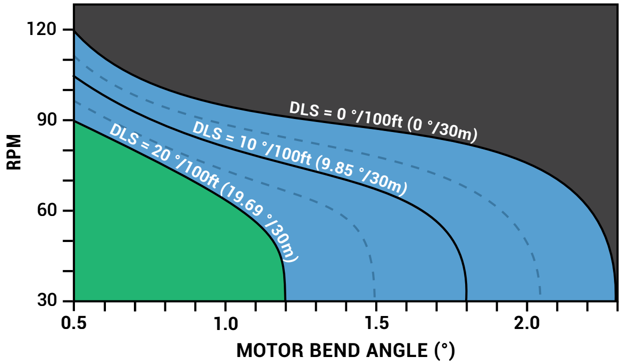
6" WELLBORE



6 ⅛" WELLBORE



6 ¼" WELLBORE



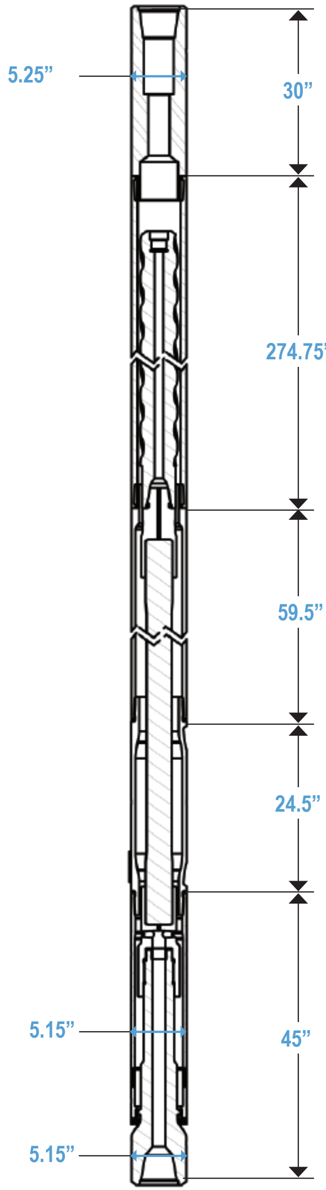
Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 5.15" 6/7 6.6

GENERAL SPECIFICATIONS	
OD	5.15 in (131 mm)
Length	36.12 ft (11.01 m)
Recommended Hole Sizes	6 - 6 3/4 in (152 - 171 mm)
Max Bend Angle	2.38°
BEARING SECTION	
Bit to Bend Length	45 in (1.143 m)
Bit Box Connection	3½ API Reg.
Max WOB	30,000 lbs (13,345 DaN)
Max Overpull for Rerun	60,000 lbs (26,689 DaN)
Overpull to Yield Motor	120,000 lbs (53,379 DaN)
Max Bit Pressure Drop	750 psi (5,171 kPa)
Opt Bit Pressure Drop	100 - 600 psi (690 - 4,136 kPa)
LCM Capability	40 lb nut plug
POWER SECTION	
Lobe Configuration	6/7
Stages	6.6
Max Differential Pressure	1,560 psi (10,700 kPa)
Stall Differential Pressure	2,450 psi (16,900 kPa)
Torque at Max Diff Pressure	8,550 ft-lbs (11,592 Nm)
Stall Torque	13,460 ft-lbs (18,249 Nm)
Flow Range	200 - 400 gal/min (760 - 1,514 L/min)
Speed Range	90 - 180 RPM
Speed Ratio	0.46 rev/gal (0.12 rev/L)
Torque Slope	5.51 ft-lb/psi (1.08 Nm/kPa)

GENERAL DIMENSIONS

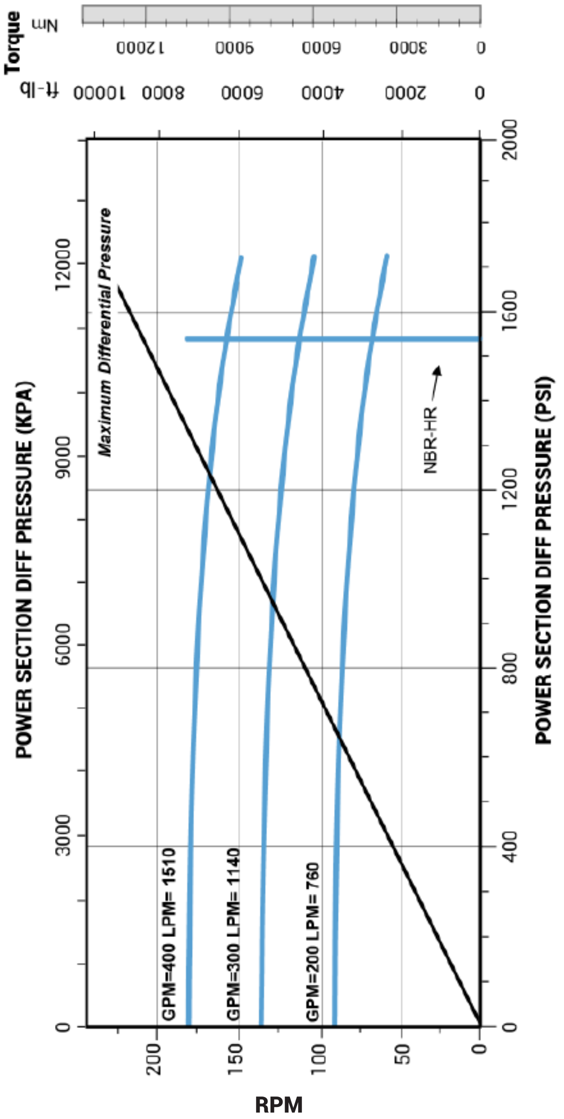
TiTAN22 | 5.15" 6/7 6.6



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 5.15" 6/7 6.6



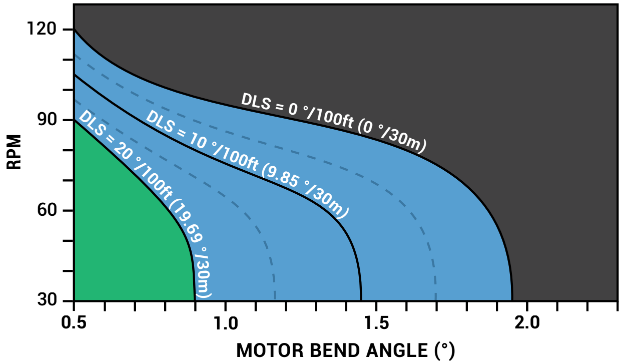
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

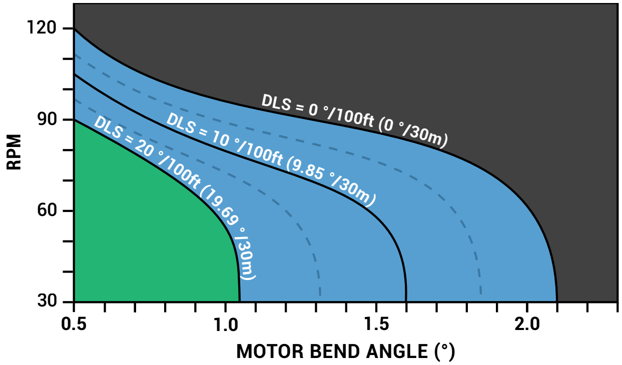
ROTATIONAL LIMIT

TiTAN22 | 5.15"

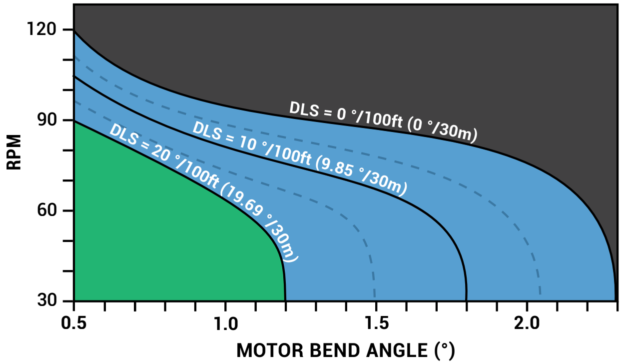
6" WELLBORE



6 ⅛" WELLBORE



6 ¼" WELLBORE



Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 5.15" 6/7 8.0

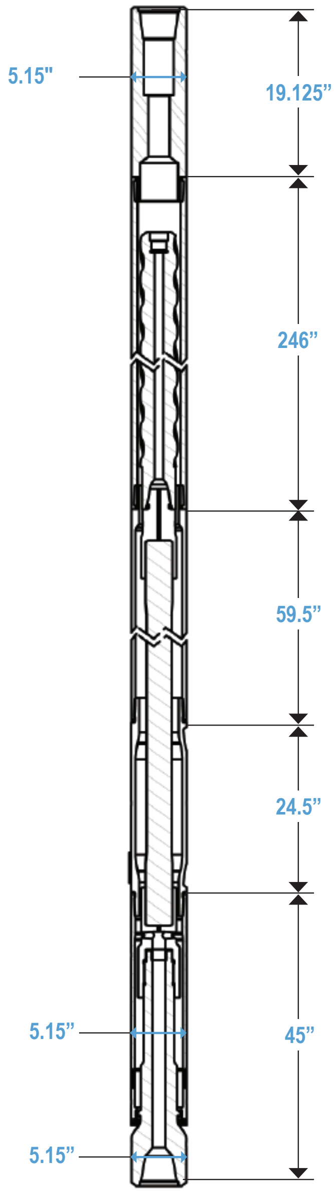
GENERAL SPECIFICATIONS	
OD	5.15 in (131 mm)
Length	32.8 ft (9.99 m)
Recommended Hole Sizes	6 - 6 ¾ in (152 - 171 mm)
Max Bend Angle	2.38°

BEARING SECTION	
Bit to Bend Length	45 in (1.143 m)
Bit Box Connection	3½ API Reg.
Max WOB	30,000 lbs (13,345 DaN)
Max Overpull for Rerun	60,000 lbs (26,689 DaN)
Overpull to Yield Motor	120,000 lbs (53,379 DaN)
Max Bit Pressure Drop	750 psi (5,171 kPa)
Opt Bit Pressure Drop	100 - 600 psi (690 - 4,136 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	6/7
Stages	8.0
Max Differential Pressure	1,880 psi (13,000 kPa)
Stall Differential Pressure	2,970 psi (20,500 kPa)
Torque at Max Diff Pressure	6,110 ft-lbs (8,300 Nm)
Stall Torque	9,630 ft-lbs (13,100 Nm)
Flow Range	150 - 350 gal/min (570 - 1,320 L/min)
Speed Range	120-280 RPM
Speed Ratio	0.79 rev/gal (0.20 rev/L)
Torque Slope	3.25 ft-lb/psi (0.64 Nm/kPa)

GENERAL DIMENSIONS

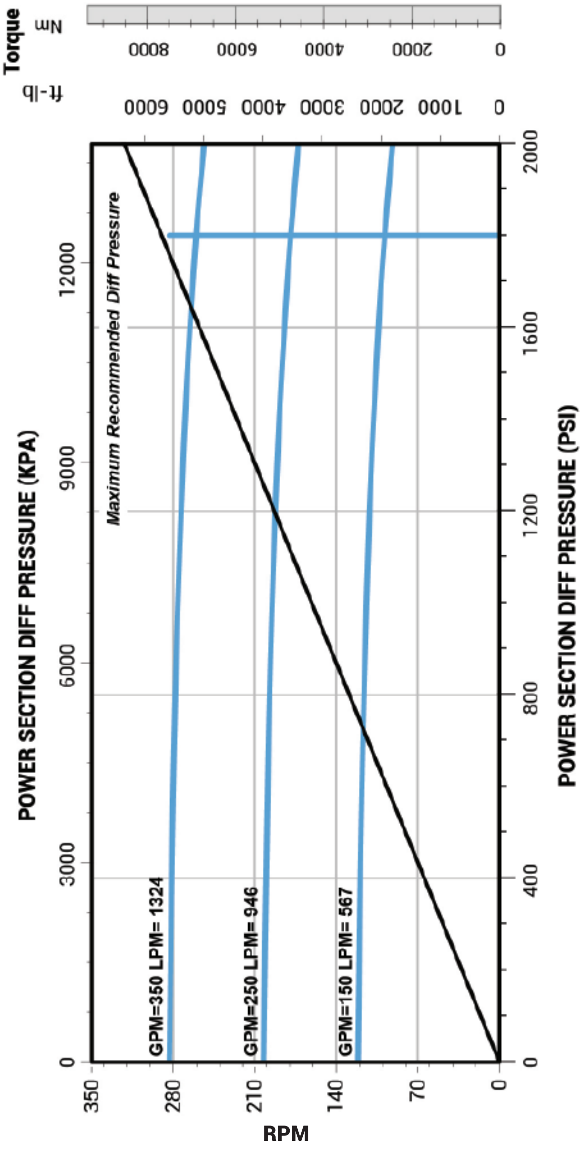
TiTAN22 | 5.15" 6/7 8.0



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 5.15" 6/7 8.0



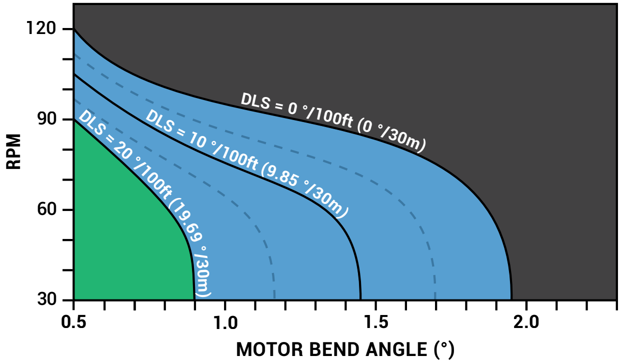
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

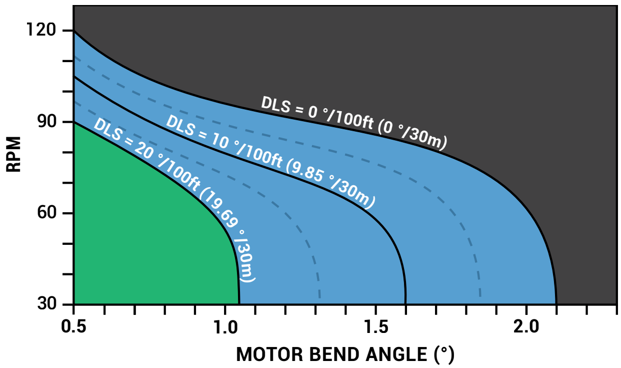
ROTATIONAL LIMIT

TiTAN22 | 5.15"

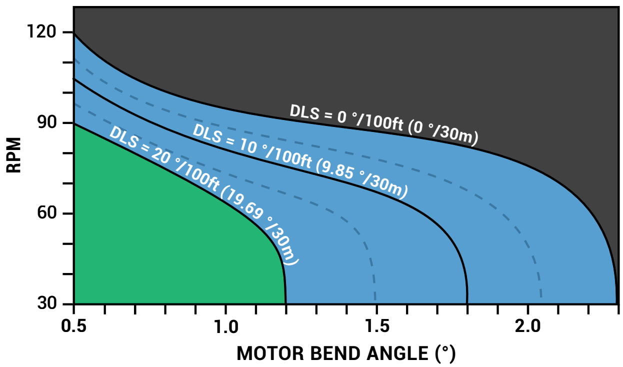
6" WELLBORE



6 ⅛" WELLBORE



6 ¼" WELLBORE



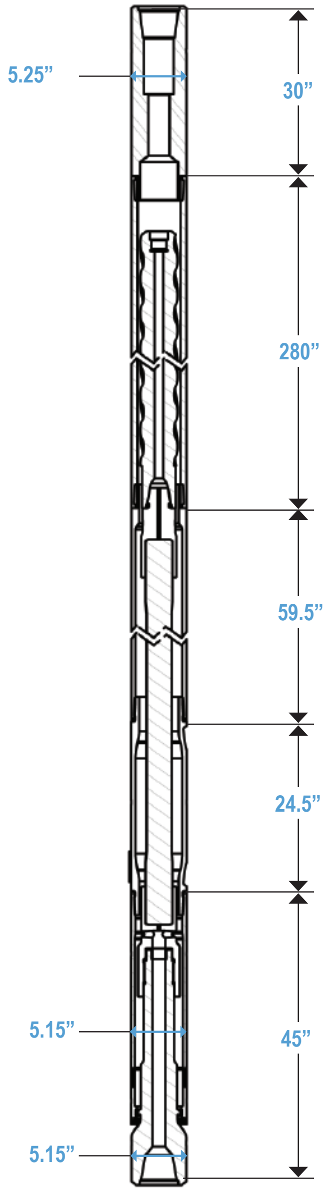
Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 5.15" 6/7 10.4

GENERAL SPECIFICATIONS	
OD	5.15 in (131 mm)
Length	36.56 ft (11.14 m)
Recommended Hole Sizes	6 - 6 3/4 in (152 - 171 mm)
Max Bend Angle	2.38°
BEARING SECTION	
Bit to Bend Length	45 in (1.14 m)
Bit Box Connection	3½ API Reg.
Max WOB	30,000 lbs (13,345 DaN)
Max Overpull for Rerun	60,000 lbs (26,689 DaN)
Overpull to Yield Motor	120,000 lbs (53,379 DaN)
Max Bit Pressure Drop	750 psi (5,171 kPa)
Opt Bit Pressure Drop	100 - 600 psi (690 - 4,136 kPa)
LCM Capability	40 lb nut plug
POWER SECTION	
Lobe Configuration	6/7
Stages	10.4
Max Differential Pressure	2,340 psi (16,130 kPa)
Stall Differential Pressure	3,510 psi (24,200 kPa)
Torque at Max Diff Pressure	8,610 ft-lbs (11,673 Nm)
Stall Torque	12,920 ft-lbs (17,517 Nm)
Flow Range	225 - 425 gal/min (852 - 1,608 L/min)
Speed Range	157 - 300 RPM
Speed Ratio	0.70 rev/gal (0.19 rev/L)
Torque Slope	3.68 ft-lb/psi (0.72 Nm/kPa)

GENERAL DIMENSIONS

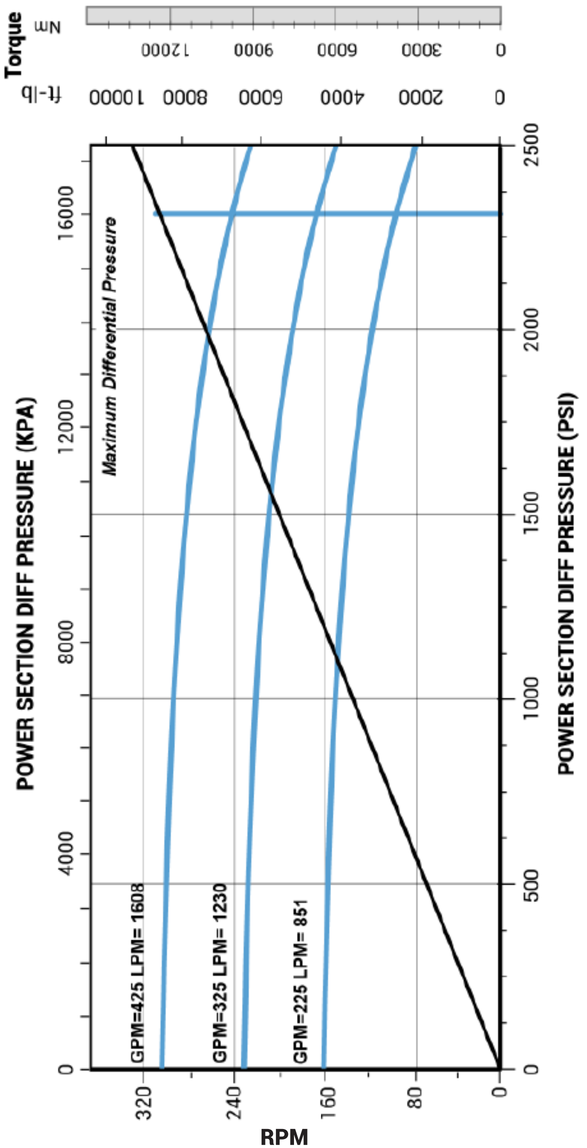
TiTAN22 | 5.15" 6/7 10.4



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 5.15" 6/7 10.4



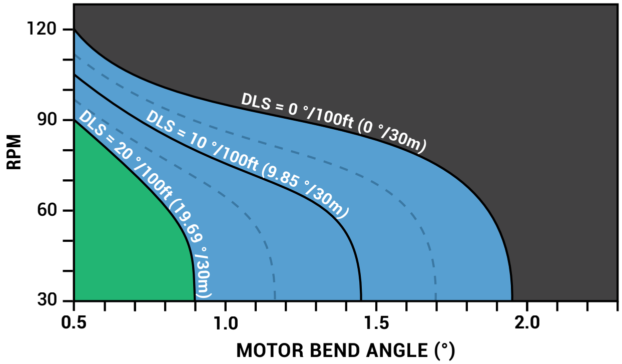
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

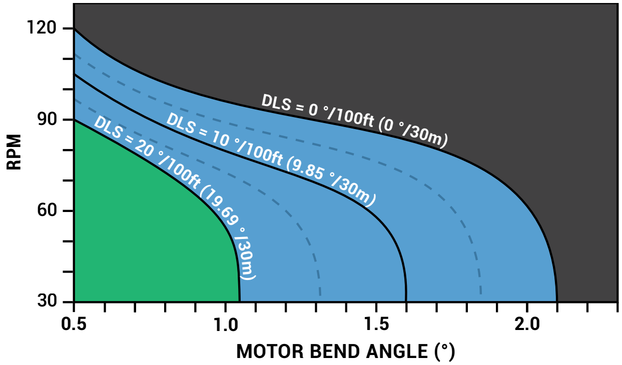
ROTATIONAL LIMIT

TiTAN22 | 5.15"

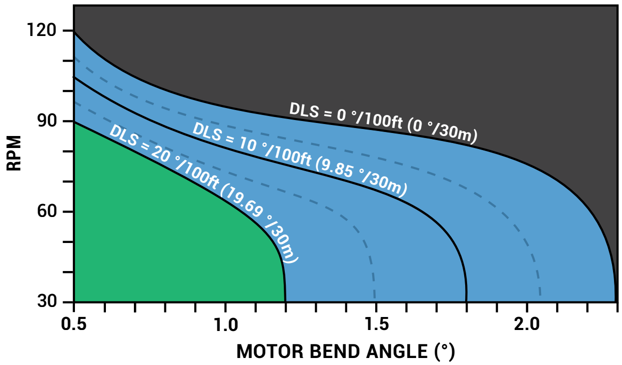
6" WELLBORE



6 ⅛" WELLBORE



6 ¼" WELLBORE



Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 6.60" 4/5 7.0

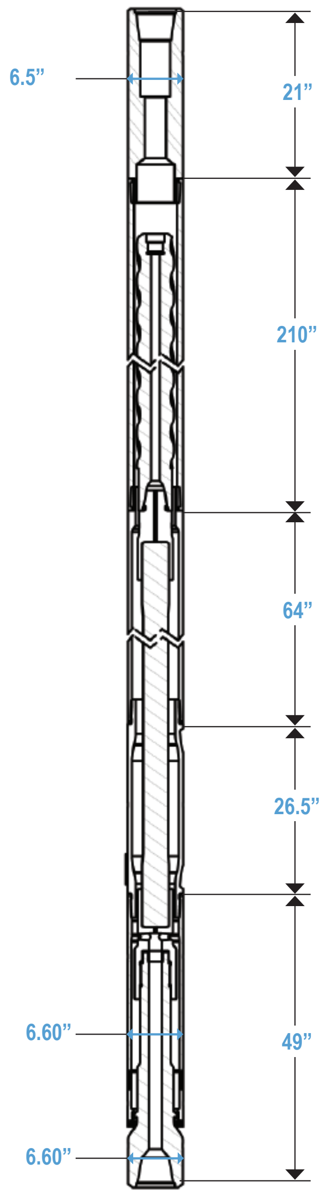
GENERAL SPECIFICATIONS	
OD	6.60 in (168 mm)
Length	30.9 ft (9.41 m)
Recommended Hole Sizes	7 7/8 - 8 3/4 in (200 - 222 mm)
Max Bend Angle	2.38°

BEARING SECTION	
Bit to Bend Length	49 in (1.244 m)
Bit Box Connection	4½ API Reg.
Max WOB	60,000 lbs (26,689 DaN)
Max Overpull for Rerun	105,000 lbs (46,706 DaN)
Overpull to Yield Motor	210,000 lbs (93,413 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	100 - 750 psi (690 - 5,171 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	4/5
Stages	7.0
Max Differential Pressure	1,650 psi (11,400 kPa)
Stall Differential Pressure	2,600 psi (17,900 kPa)
Torque at Max Diff Pressure	8,820 ft-lbs (12,000 Nm)
Stall Torque	13,890 ft-lbs (18,900 Nm)
Flow Range	300-600 gal/min (1,140 - 2,270 L/min)
Speed Range	150 - 300 RPM
Speed Ratio	0.49 rev/gal (0.13 rev/L)
Torque Slope	5.36 ft-lb/psi (1.05 Nm/kPa)

GENERAL DIMENSIONS

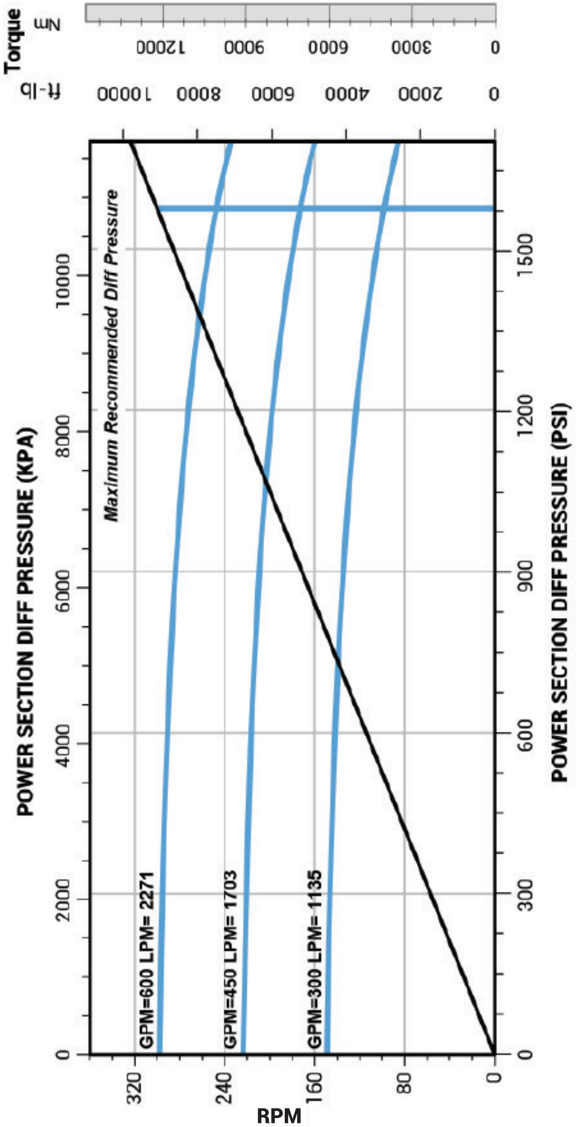
TiTAN22 | 6.60" 4/5 7.0



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 6.60" 4/5 7.0



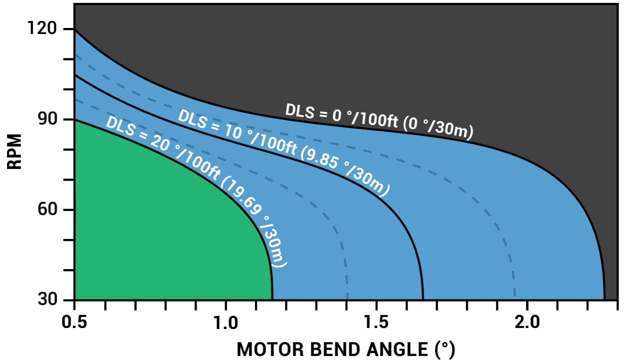
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

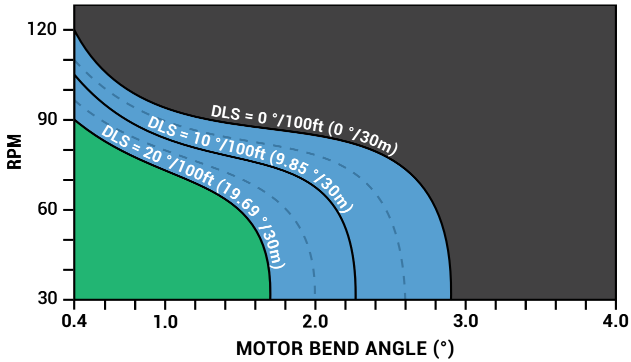
ROTATIONAL LIMIT

TiTAN22 | 6.60"

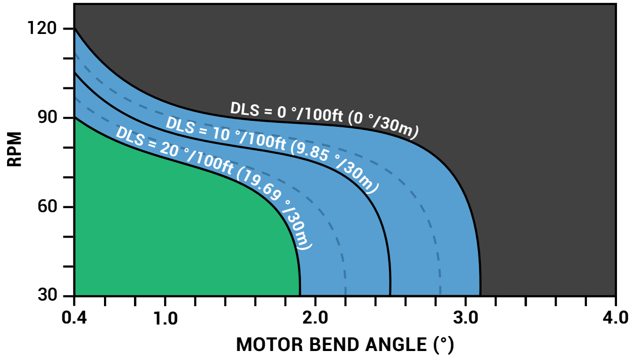
7⅞" WELLBORE



8½" WELLBORE



8¾" WELLBORE



Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 6.60" 5/6 8.3

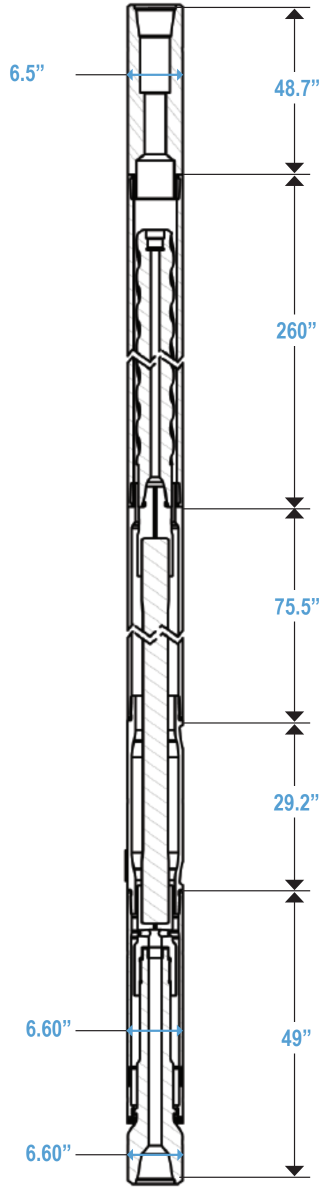
GENERAL SPECIFICATIONS	
OD	6.60 in (168 mm)
Length	38.5 ft (11.73 m)
Recommended Hole Sizes	7 7/8 - 8 3/4 in (200 - 222 mm)
Max Bend Angle	2.38°

BEARING SECTION	
Bit to Bend Length	49 in (1.244 m)
Bit Box Connection	4½ API Reg.
Max WOB	60,000 lbs (26,689 DaN)
Max Overpull for Rerun	105,000 lbs (46,706 DaN)
Overpull to Yield Motor	210,000 lbs (93,413 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	100 - 750 psi (690 - 5,171 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	5/6
Stages	8.3
Max Differential Pressure	1,960 psi (13,500 kPa)
Stall Differential Pressure	3,080 psi (21,200 kPa)
Torque at Max Diff Pressure	13,030 ft-lbs (17,700 Nm)
Stall Torque	20,530 ft-lbs (27,900 Nm)
Flow Range	350-750 gal/min (1,320 - 2,840 L/min)
Speed Range	130 - 290 RPM
Speed Ratio	0.38 rev/gal (0.10 rev/L)
Torque Slope	6.68 ft-lb/psi (1.31 Nm/kPa)

GENERAL DIMENSIONS

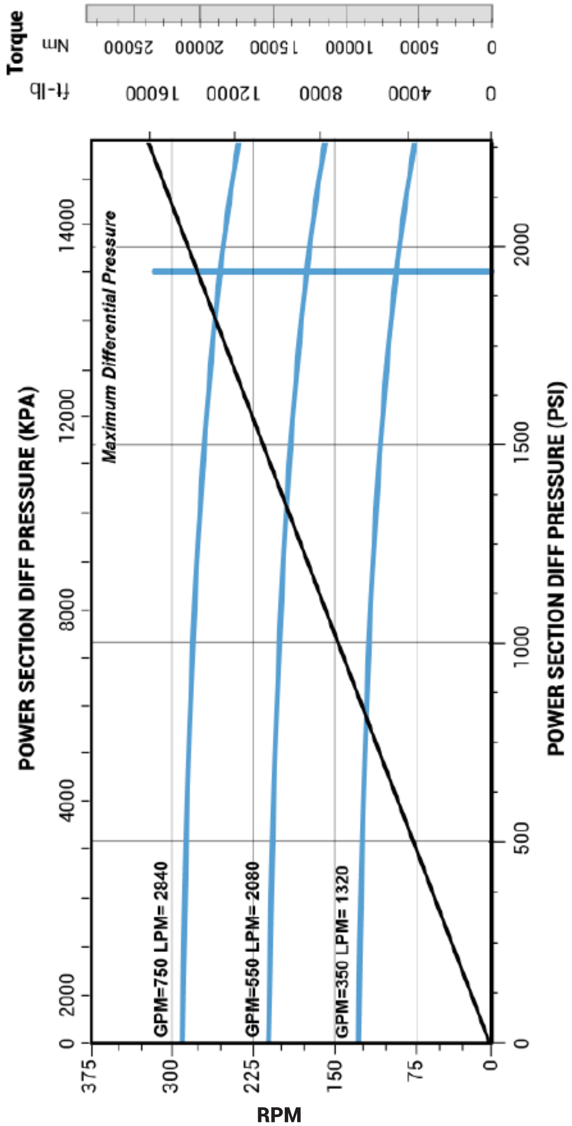
TiTAN22 | 6.60" 5/6 8.3



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 6.60" 5/6 8.3

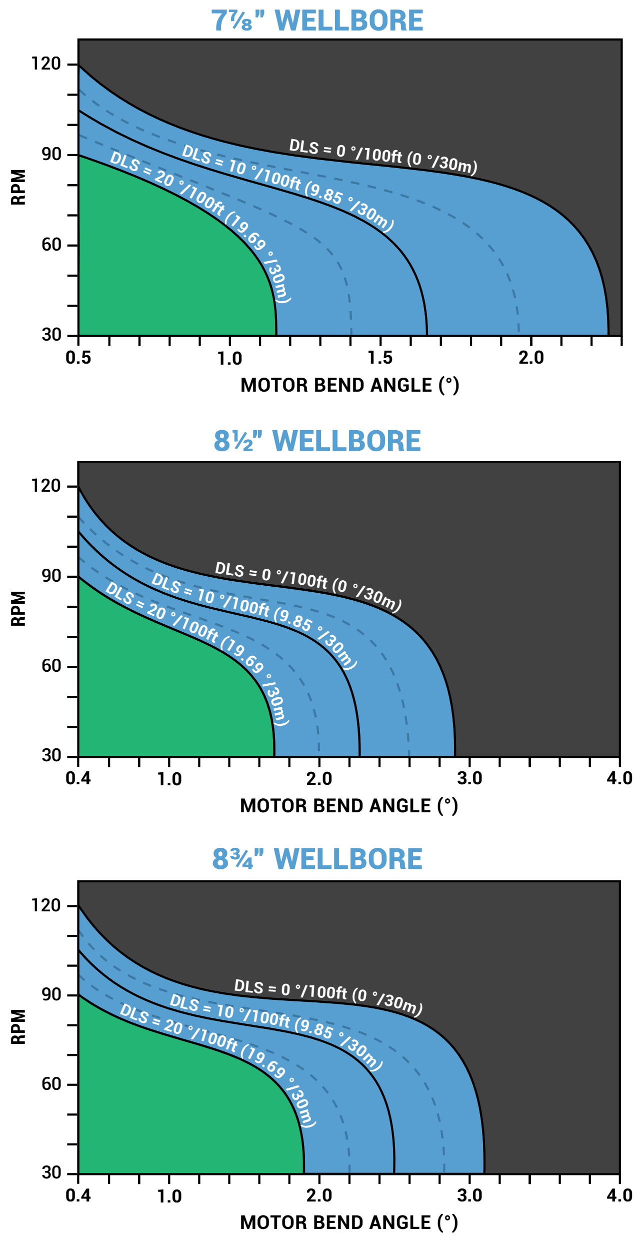


***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

ROTATIONAL LIMIT

TiTAN22 | 6.60"



Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 6.60" 7/8 3.3

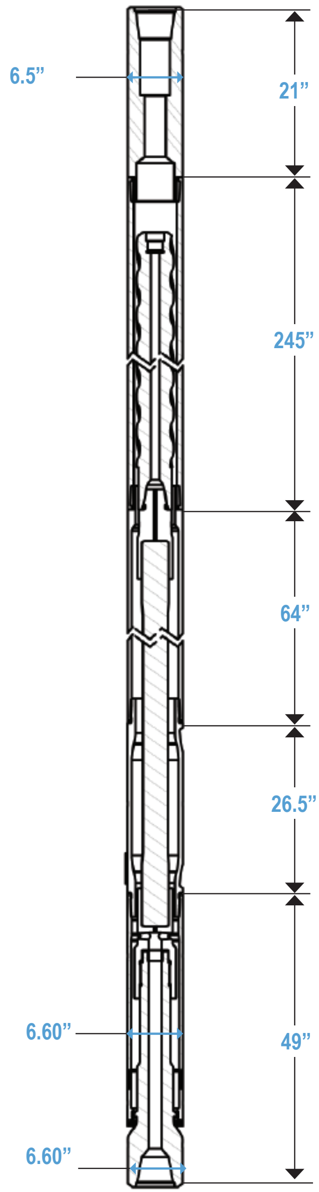
GENERAL SPECIFICATIONS	
OD	6.60 in (168 mm)
Length	33.8 ft (10.3 m)
Recommended Hole Sizes	7 7/8 - 8 3/4 in (200 - 222 mm)
Max Bend Angle	2.38°

BEARING SECTION	
Bit to Bend Length	49 in (1.244 m)
Bit Box Connection	4½ API Reg.
Max WOB	60,000 lbs (26,689 DaN)
Max Overpull for Rerun	105,000 lbs (46,706 DaN)
Overpull to Yield Motor	210,000 lbs (93,413 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	100 - 750 psi (690 - 5,171 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	7/8
Stages	3.3
Max Differential Pressure	780 psi (5,400 kPa)
Stall Differential Pressure	1,230 psi (8,500 kPa)
Torque at Max Diff Pressure	13,150 ft-lbs (17,900 Nm)
Stall Torque	20,710 ft-lbs (28,100 Nm)
Flow Range	300-600 gal/min (1,140 - 2,270 L/min)
Speed Range	50 - 90 RPM
Speed Ratio	0.15 rev/gal (0.04 rev/L)
Torque Slope	16.95 ft-lb/psi (3.33 Nm/kPa)

GENERAL DIMENSIONS

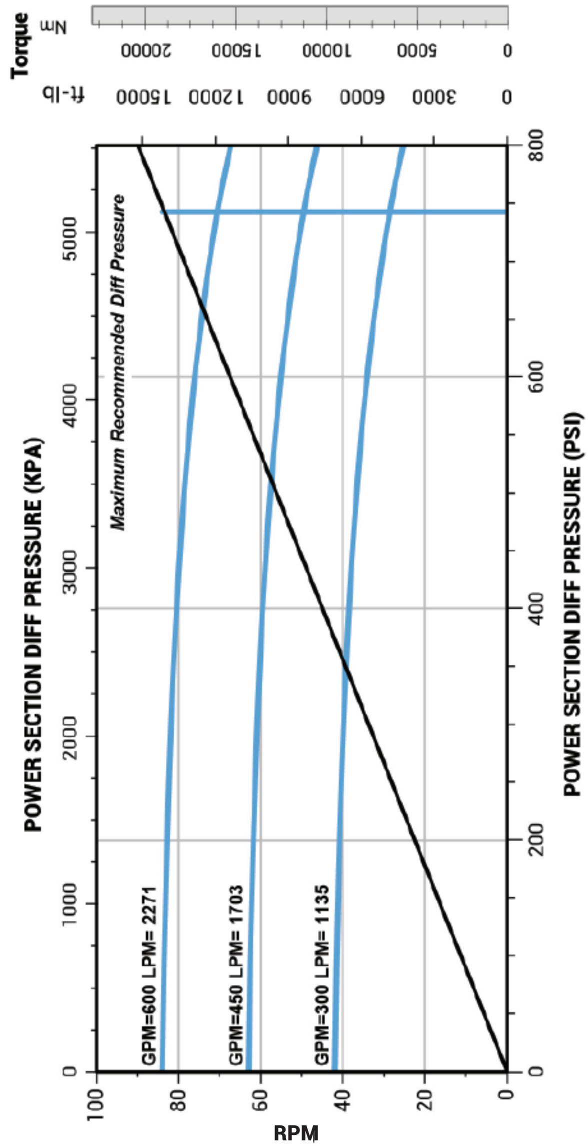
TiTAN22 | 6.60" 7/8 3.3



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 6.60" 7/8 3.3



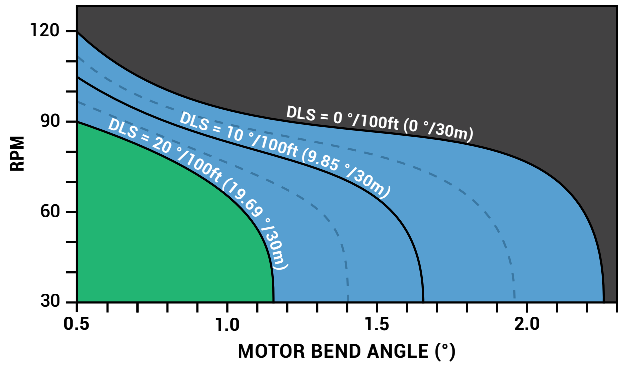
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

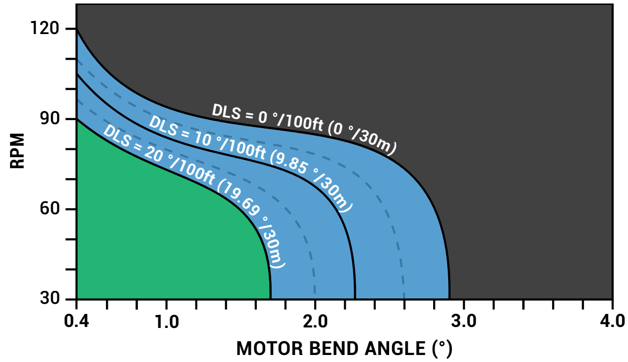
ROTATIONAL LIMIT

TiTAN22 | 6.60"

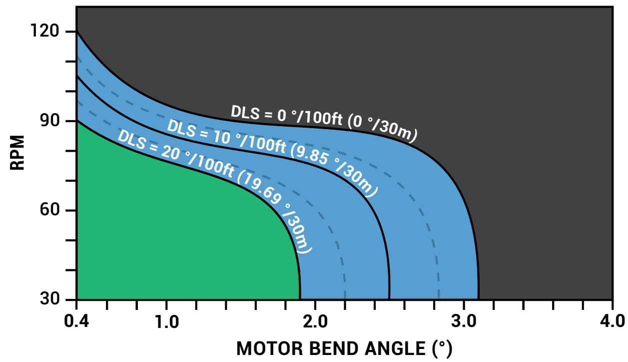
7⅞" WELLBORE



8½" WELLBORE



8¾" WELLBORE



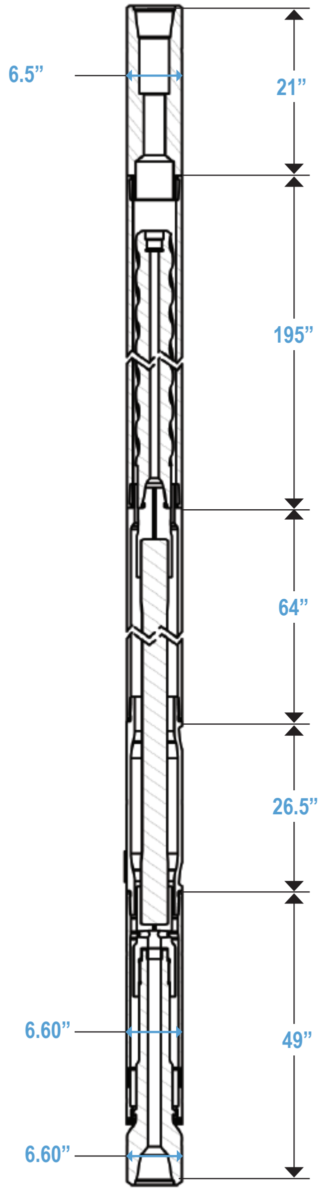
Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 6.60" 7/8 5.0

GENERAL SPECIFICATIONS	
OD	6.60 in (168 mm)
Length	29.6 ft (9.02 m)
Recommended Hole Sizes	7 7/8 - 8 3/4 in (200 - 222 mm)
Max Bend Angle	2.38°
BEARING SECTION	
Bit to Bend Length	49 in (1.244 m)
Bit Box Connection	4½ API Reg.
Max WOB	60,000 lbs (26,689 DaN)
Max Overpull for Rerun	105,000 lbs (46,706 DaN)
Overpull to Yield Motor	210,000 lbs (93,413 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	100 - 750 psi (690 - 5,171 kPa)
LCM Capability	40 lb nut plug
POWER SECTION	
Lobe Configuration	7/8
Stages	5.0
Max Differential Pressure	1,180 psi (8,200 kPa)
Stall Differential Pressure	1,860 psi (12,800 kPa)
Torque at Max Diff Pressure	10,650 ft-lbs (14,500 Nm)
Stall Torque	16,770 ft-lbs (22,800 Nm)
Flow Range	300-650 gal/min (1,140 - 2,460 L/min)
Speed Range	80 - 188 RPM
Speed Ratio	0.29 rev/gal (0.08 rev/L)
Torque Slope	9.06 ft-lb/psi (1.78 Nm/kPa)

GENERAL DIMENSIONS

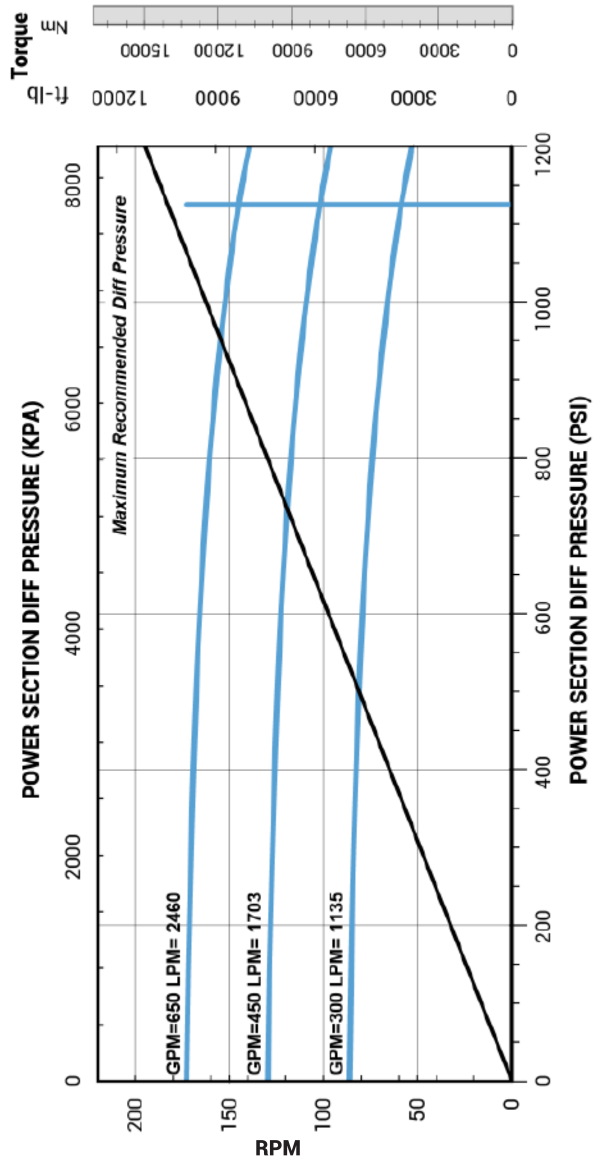
TiTAN22 | 6.60" 7/8 5.0



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 6.60" 7/8 5.0



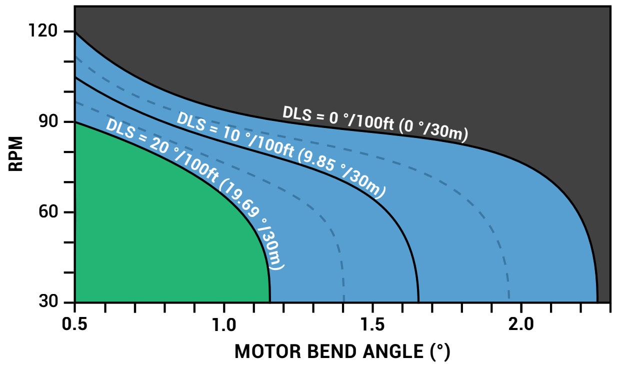
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

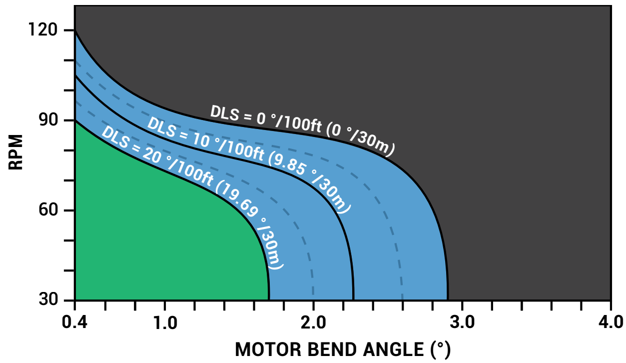
ROTATIONAL LIMIT

TiTAN22 | 6.60"

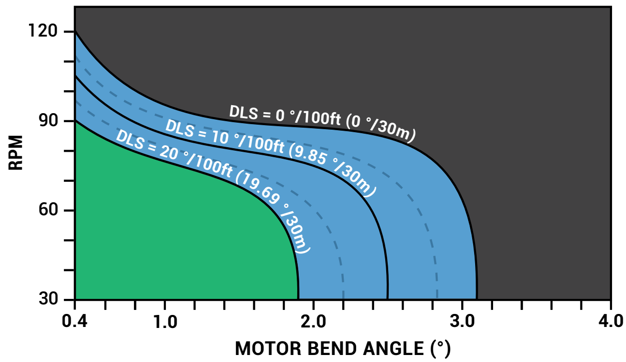
7⅞" WELLBORE



8½" WELLBORE



8¾" WELLBORE



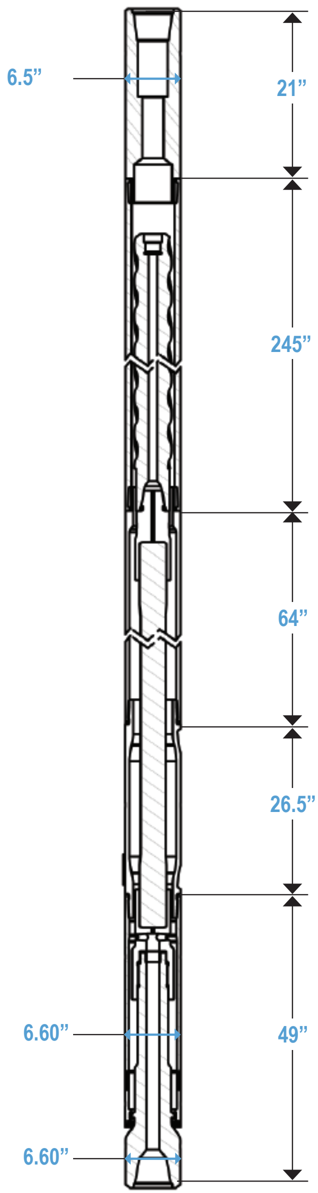
Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 6.60" 7/8 6.4

GENERAL SPECIFICATIONS	
OD	6.60 in (168 mm)
Length	33.8 ft (10.3 m)
Recommended Hole Sizes	7 7/8 - 8 3/4 in (200 - 222 mm)
Max Bend Angle	2.38°
BEARING SECTION	
Bit to Bend Length	49 in (1.244 m)
Bit Box Connection	4½ API Reg.
Max WOB	60,000 lbs (26,689 DaN)
Max Overpull for Rerun	105,000 lbs (46,706 DaN)
Overpull to Yield Motor	210,000 lbs (93,413 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	100 - 750 psi (690 - 5,171 kPa)
LCM Capability	40 lb nut plug
POWER SECTION	
Lobe Configuration	7/8
Stages	6.4
Max Differential Pressure	1,510 psi (10,400 kPa)
Stall Differential Pressure	2,370 psi (16,400 kPa)
Torque at Max Diff Pressure	13,360 ft-lbs (18,500 Nm)
Stall Torque	21,470 ft-lbs (29,100 Nm)
Flow Range	300-650 gal/min (1,140 - 2,460 L/min)
Speed Range	80 - 188 RPM
Speed Ratio	0.29 rev/gal (0.08 rev/L)
Torque Slope	9.06 ft-lb/psi (1.78 Nm/kPa)

GENERAL DIMENSIONS

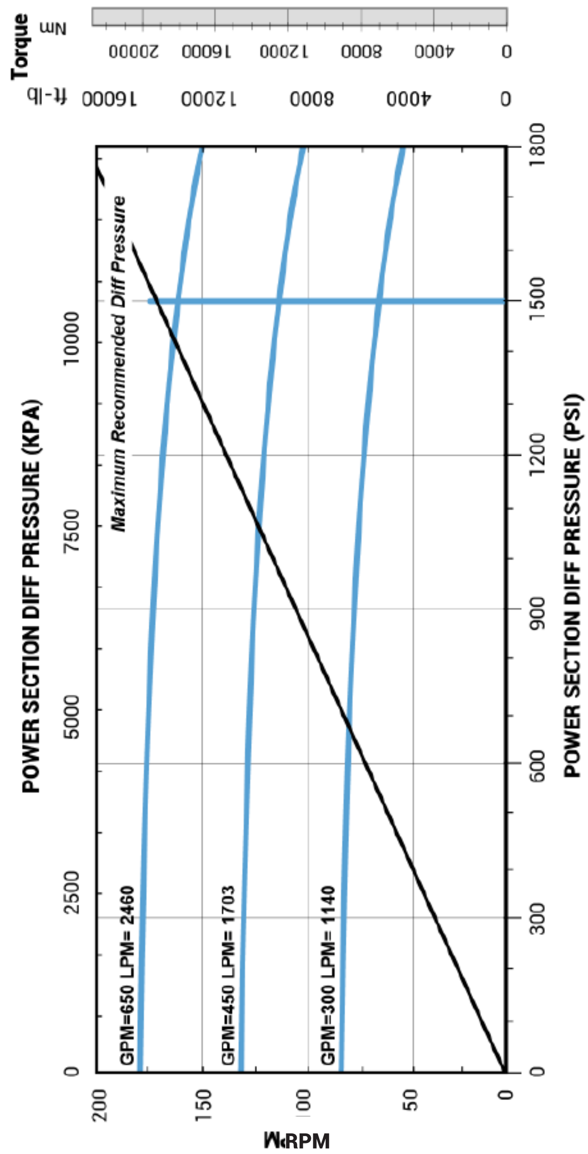
TiTAN22 | 6.60" 7/8 6.4



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 6.60" 7/8 6.4



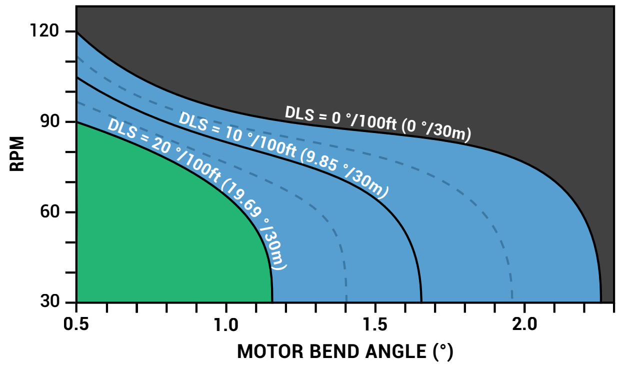
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

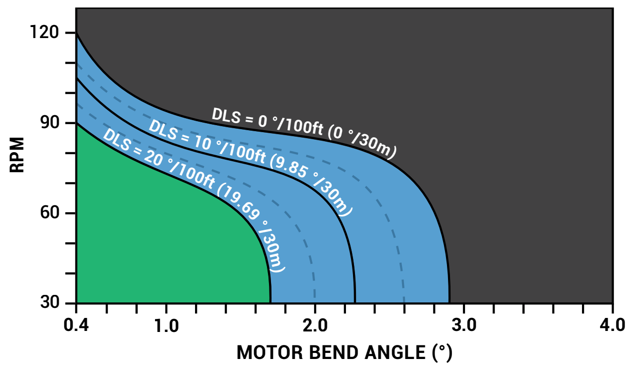
ROTATIONAL LIMIT

TiTAN22 | 6.60"

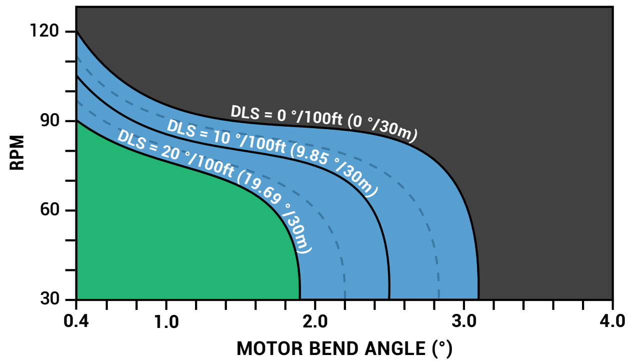
7⅞" WELLBORE



8½" WELLBORE



8¾" WELLBORE



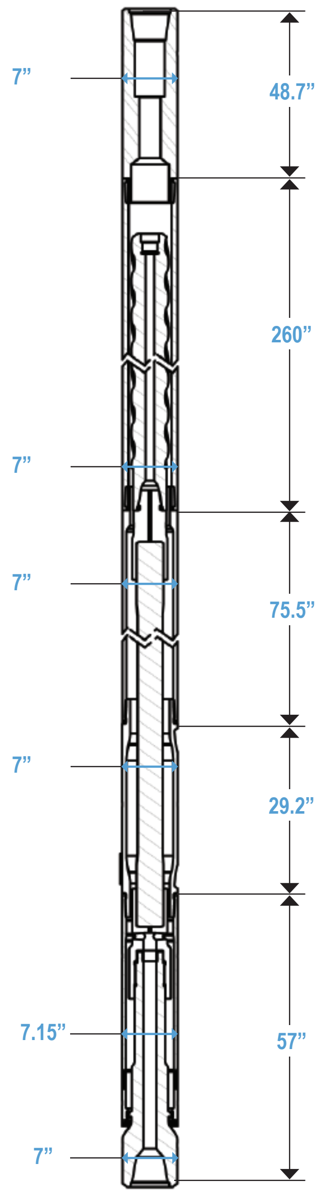
Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 7.15" 5/6 8.3

GENERAL SPECIFICATIONS	
OD	7.15 in (181 mm)
Length	39.2 ft (11.94 m)
Recommended Hole Sizes	8 1/2 - 9 7/8 in (215 - 250 mm)
Max Bend Angle	2.12°
BEARING SECTION	
Bit to Bend Length	57 in (1.44 m)
Bit Box Connection	4½ in API Reg. Box
Max WOB	60,000 lbs (26,689 DaN)
Max Overpull for Rerun	110,000 lbs (48,930 DaN)
Overpull to Yield Motor	240,000 lbs (106,757 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	100 - 750 psi (690 - 5,171 kPa)
LCM Capability	40 lb nut plug
POWER SECTION	
Lobe Configuration	5/6
Stages	8.3
Max Differential Pressure	1,960 psi (13,500 kPa)
Stall Differential Pressure	3,080 ft-lbs (21,200 Nm)
Torque at Max Diff Pressure	13,030 ft-lbs (17,700 Nm)
Stall Torque	20,530 ft-lbs (27,900 Nm)
Flow Range	350-750 gal/min (1,320-2,840 L/min)
Speed Range	130 - 290 RPM
Speed Ratio	0.38 rev/gal (0.10 rev/L)
Torque Slope	6.68 ft-lb/psi (1.31 Nm/kPa)

GENERAL DIMENSIONS

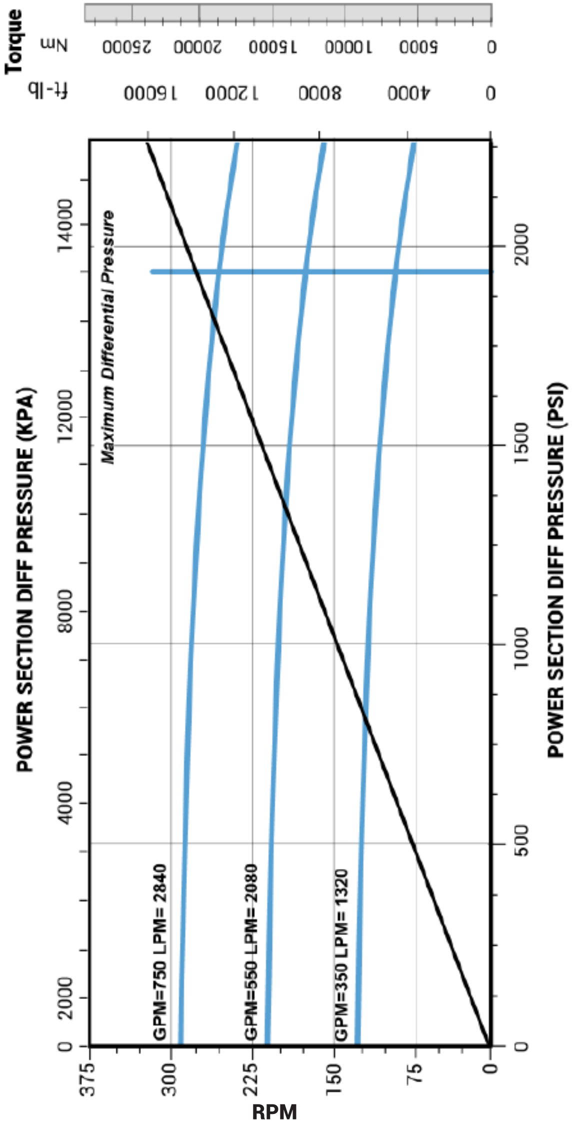
TiTAN22 | 7.15" 5/6 8.3



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 7.15" 5/6 8.3



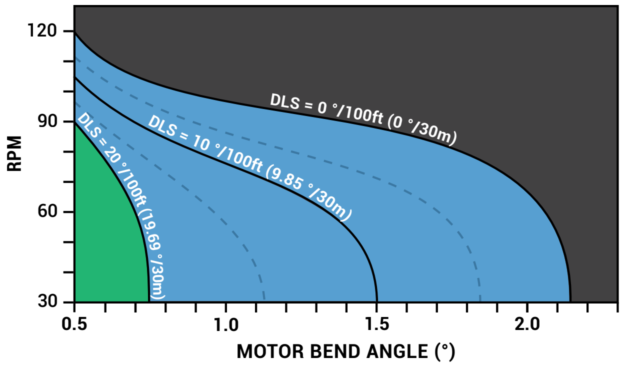
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

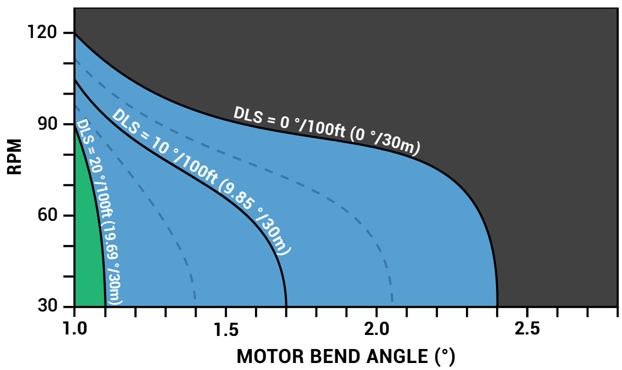
ROTATIONAL LIMIT

TiTAN22 | 7.15"

8½" WELLBORE



8¾" WELLBORE



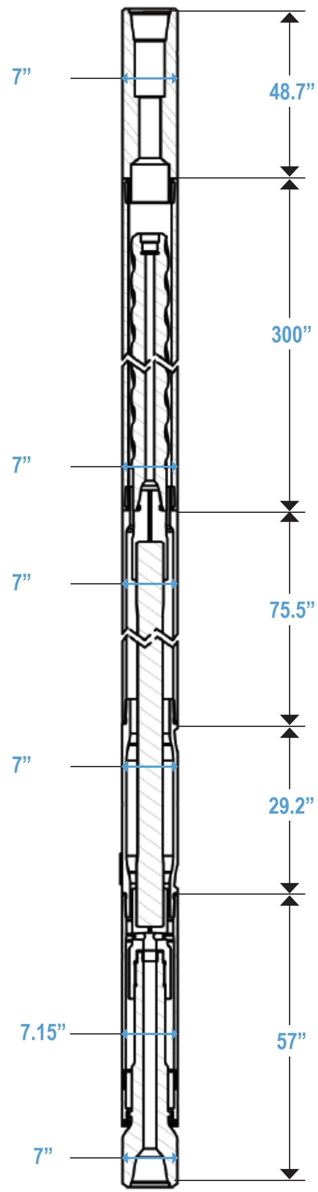
Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 7.15" 5/6 11.2

GENERAL SPECIFICATIONS	
OD	7.15 in (181 mm)
Length	42.5 ft (12.95 m)
Recommended Hole Sizes	8 1/2 - 9 7/8 in (215 - 250 mm)
Max Bend Angle	2.12°
BEARING SECTION	
Bit to Bend Length	57 in (1.44 m)
Bit Box Connection	4½ in API Reg. Box
Max WOB	60,000 lbs (26,689 DaN)
Max Overpull for Rerun	110,000 lbs (48,930 DaN)
Overpull to Yield Motor	240,000 lbs (106,757 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	100 - 750 psi (690 - 5,171 kPa)
LCM Capability	40 lb nut plug
POWER SECTION	
Lobe Configuration	5/6
Stages	11.2
Max Differential Pressure	2,520 psi (17,374 kPa)
Stall Differential Pressure	3,780 psi (26,060 kPa)
Torque at Max Diff Pressure	16,420 ft-lbs (22,260 Nm)
Stall Torque	24,630 ft-lbs (33,393 Nm)
Flow Range	450-750 gal/min (1,703 - 2,840 L/min)
Speed Range	180 - 300 RPM
Speed Ratio	0.40 rev/gal (0.11 rev/L)
Torque Slope	6.51 ft-lb/psi (1.28 Nm/kPa)

GENERAL DIMENSIONS

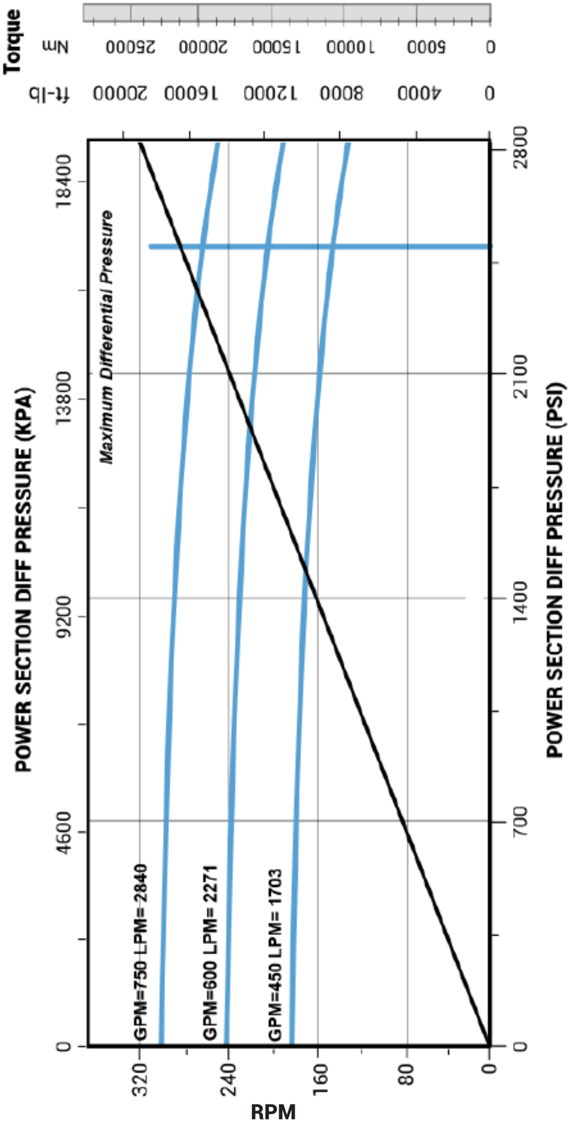
TiTAN22 | 7.15" 5/6 11.2



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 7.15" 5/6 11.2



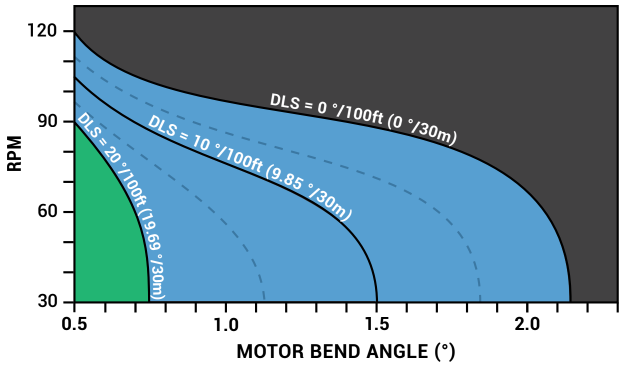
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

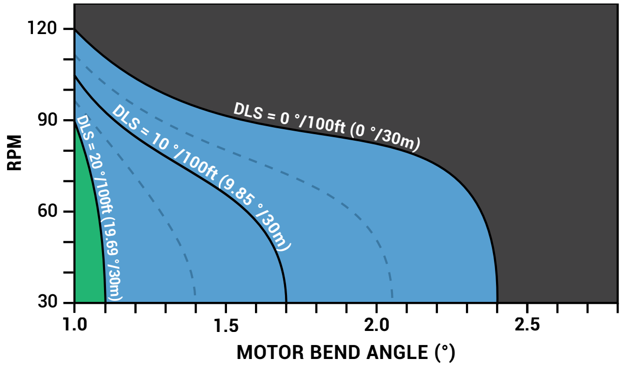
ROTATIONAL LIMIT

TiTAN22 | 7.15"

8½" WELLBORE



8¾" WELLBORE



Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 7.15" 6/7 7.1

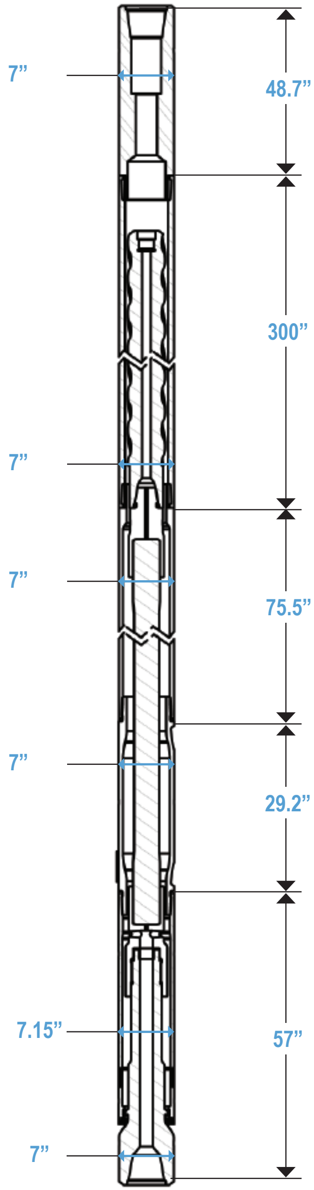
GENERAL SPECIFICATIONS	
OD	7.15 in (181 mm)
Length	42.5 ft (12.95 m)
Recommended Hole Sizes	8 1/2 - 9 7/8 in (215 - 250 mm)
Max Bend Angle	2.12°

BEARING SECTION	
Bit to Bend Length	57 in (1.44 m)
Bit Box Connection	4½ in API Reg. Box
Max WOB	60,000 lbs (26,689 DaN)
Max Overpull for Rerun	110,000 lbs (48,930 DaN)
Overpull to Yield Motor	240,000 lbs (106,757 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	100 - 750 psi (690 - 5,171 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	6/7
Stages	7.1
Max Differential Pressure	1,670 psi (11,600 kPa)
Stall Differential Pressure	2,630 psi (18,200 kPa)
Torque at Max Diff Pressure	18,230 ft-lbs (24,716 Nm)
Stall Torque	28,700 ft-lbs (39,000 Nm)
Flow Range	350-750 gal/min (1,324 - 2,840 L/min)
Speed Range	80 - 170 RPM
Speed Ratio	0.23 rev/gal (0.06 rev/L)
Torque Slope	10.92 ft-lb/psi (2.15 Nm/kPa)

GENERAL DIMENSIONS

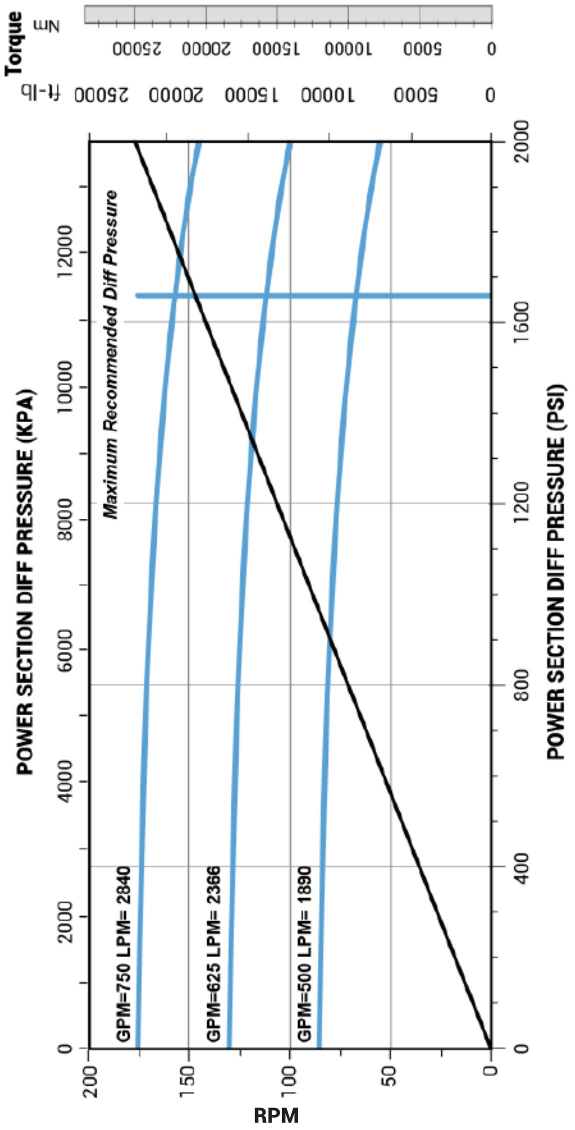
TiTAN22 | 7.15" 6/7 7.1



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 7.15" 6/7 7.1



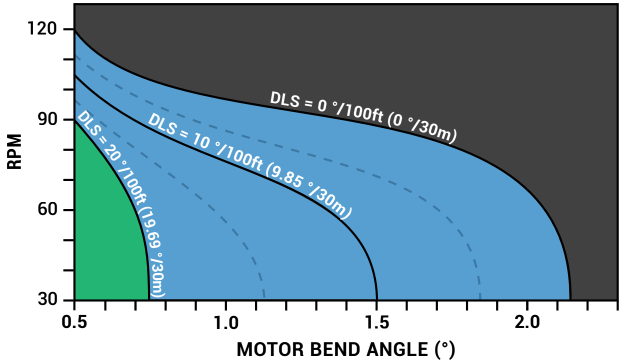
***(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

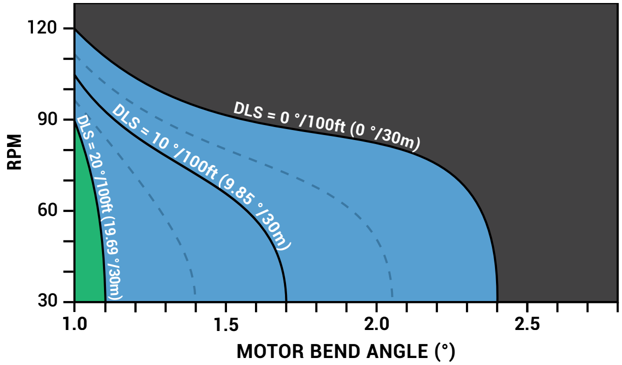
ROTATIONAL LIMIT

TiTAN22 | 7.15"

8½" WELLBORE



8¾" WELLBORE



Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 7.15" 7/8 9.4

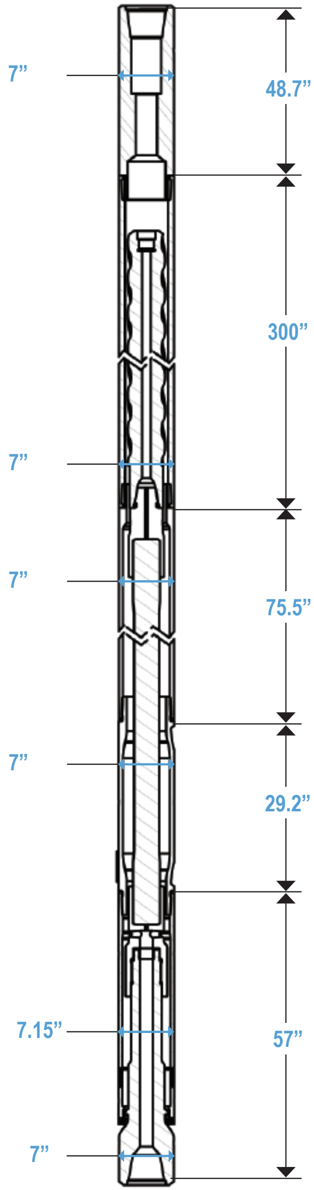
GENERAL SPECIFICATIONS	
OD	7.15 in (181 mm)
Length	42.5 ft (12.95 m)
Recommended Hole Sizes	8 1/2 - 9 7/8 in (215 - 250 mm)
Max Bend Angle	2.12°

BEARING SECTION	
Bit to Bend Length	57 in (1.44 m)
Bit Box Connection	4½ in API Reg. Box
Max WOB	60,000 lbs (26,689 DaN)
Max Overpull for Rerun	110,000 lbs (48,930 DaN)
Overpull to Yield Motor	240,000 lbs (106,757 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	100 - 750 psi (690 - 5,171 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	7/8
Stages	9.4
Max Differential Pressure	2,120 psi (14,580 kPa)
Stall Differential Pressure	3,170 psi (21,870 kPa)
Torque at Max Diff Pressure	18,680 ft-lbs (25,330 Nm)
Stall Torque	28,020 ft-lbs (37,990 Nm)
Flow Range	500-750 gal/min (1,893 - 2,839 L/min)
Speed Range	144 - 216 RPM
Speed Ratio	0.28 rev/gal (0.08 rev/L)
Torque Slope	8.83 ft-lb/psi (1.73 Nm/kPa)

GENERAL DIMENSIONS

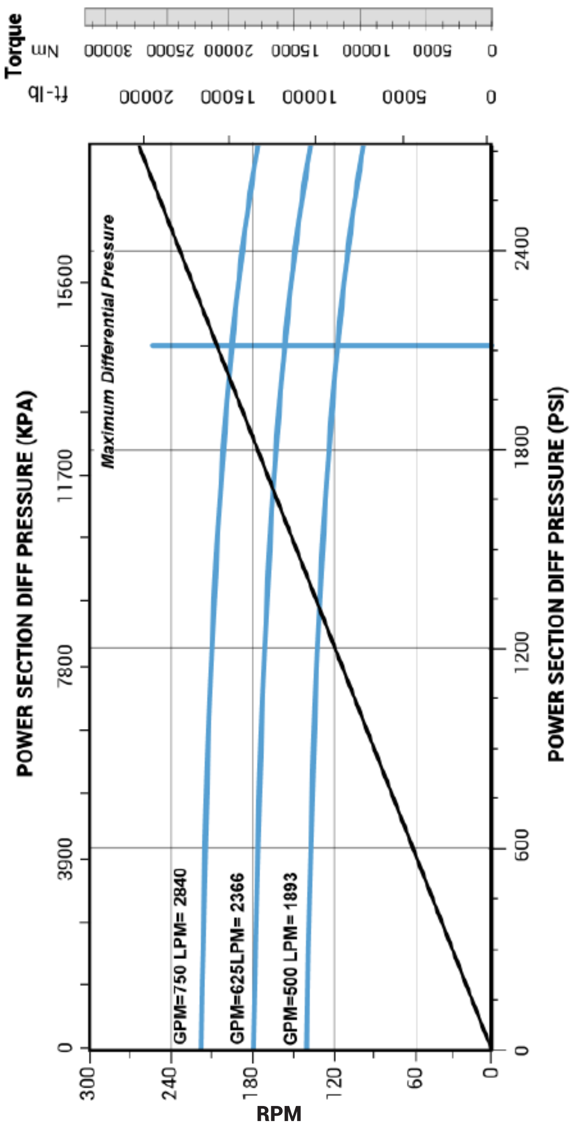
TiTAN22 | 7.15" 7/8 9.4



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 7.15" 7/8 9.4



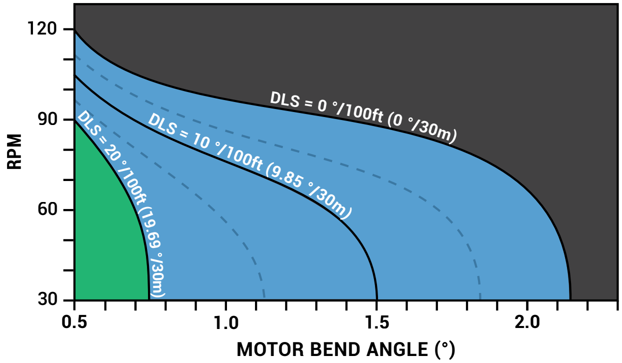
*(Right) The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

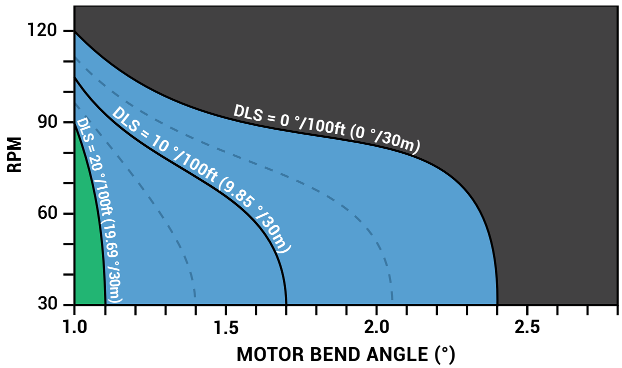
ROTATIONAL LIMIT

TiTAN22 | 7.15"

8½" WELLBORE



8¾" WELLBORE



Refer to full rotational limits disclaimer in the appendix prior to use

TiTAN22 | 9.15" 7/8 4.0

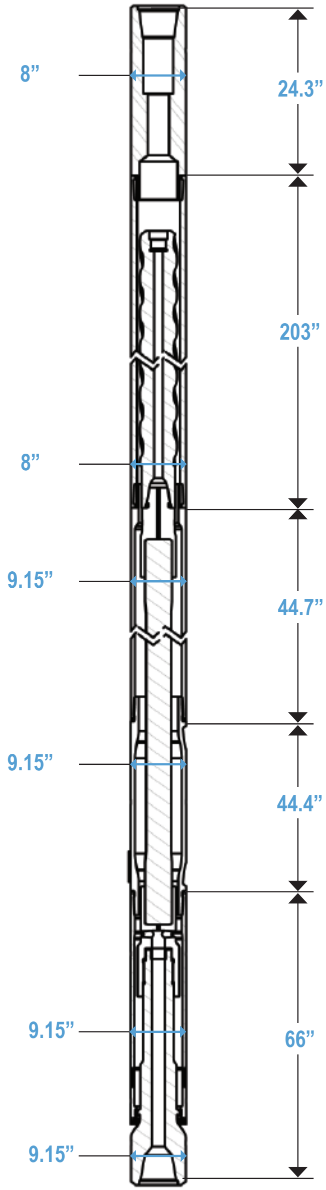
GENERAL SPECIFICATIONS	
OD	9.15 in. (232.41 mm)
Length	32 ft (9.75 m)
Recommended Hole Sizes	12 1/4-26 in (311.15-660.40 mm)
Max Bend Angle	1.83°

BEARING SECTION	
Bit to Bend Length	66 in. (1.67 m)
Bit Box Connection	6 5/8 in., 7 5/8 in API Reg. Box
Max WOB	120,000 lbs (53,378 DaN)
Max Overpull for Rerun	100,000 lbs (48,930 DaN)
Overpull to Yield Motor	250,000 lbs (111,205 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	250-900 psi (1,723-6,205 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	7/8
Stages	4.0
Max Differential Pressure	940 psi (6,895 kPa)
Stall Differential Pressure	1,490 psi (10,200 kPa)
Torque at Max Diff Pressure	14,830 ft-lbs (20,100 Nm)
Stall Torque	23,350 ft-lbs (31,700 Nm)
Flow Range	400-900 gal/min (1,510-3,410 L/min)
Speed Range	60 - 140 RPM
Speed Ratio	0.15 rev/gal (0.04 rev/L)
Torque Slope	15.77 ft-lb/psi (3.10 Nm/kPa)

GENERAL DIMENSIONS

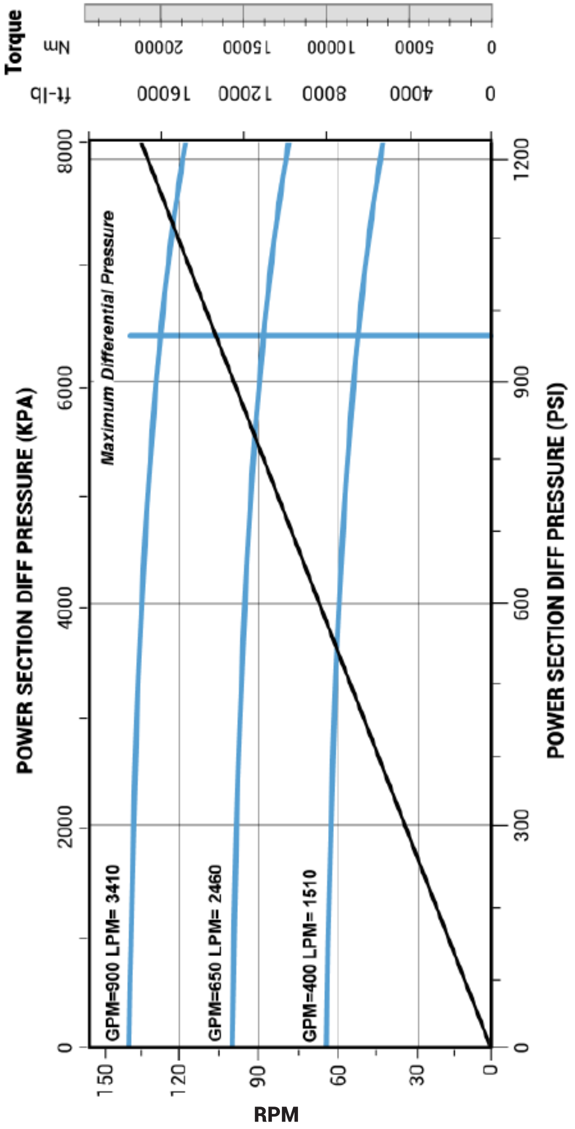
TiTAN22 | 9.15" 7/8 4.0



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 9.15" 7/8 4.0



***(Right)** **The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

TiTAN22 | 9.15" 7/8 5.7

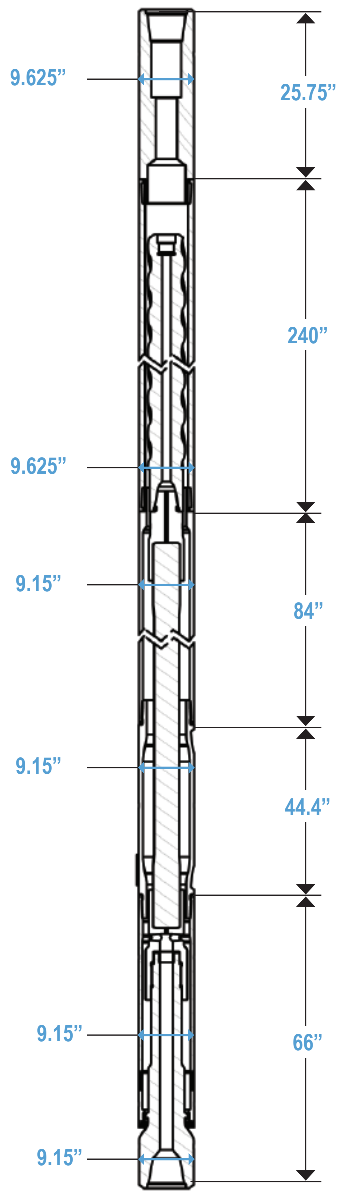
GENERAL SPECIFICATIONS	
OD	9.15 in. (232.41 mm)
Length	38.34 ft (11.68 m)
Recommended Hole Sizes	12 1/4-26 in (311.15-660.40 mm)
Max Bend Angle	1.83°

BEARING SECTION	
Bit to Bend Length	66 in. (1.67 m)
Bit Box Connection	6 5/8 in., 7 5/8 in API Reg. Box
Max WOB	120,000 lbs (53,378 DaN)
Max Overpull for Rerun	100,000 lbs (48,930 DaN)
Overpull to Yield Motor	250,000 lbs (111,205 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	250-900 psi (1,723-6,205 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	7/8
Stages	5.7
Max Differential Pressure	1,340 psi (9,300 kPa)
Stall Differential Pressure	2,110 psi (14,600 kPa)
Torque at Max Diff Pressure	25,920 ft-lbs (35,200 Nm)
Stall Torque	40,830 ft-lbs (55,400 Nm)
Flow Range	600-1,200 gal/min (2,270-4,540 L/min)
Speed Range	80 - 150 RPM
Speed Ratio	0.12 rev/gal (0.03 rev/L)
Torque Slope	19.35 ft-lb/psi (3.81 Nm/kPa)

GENERAL DIMENSIONS

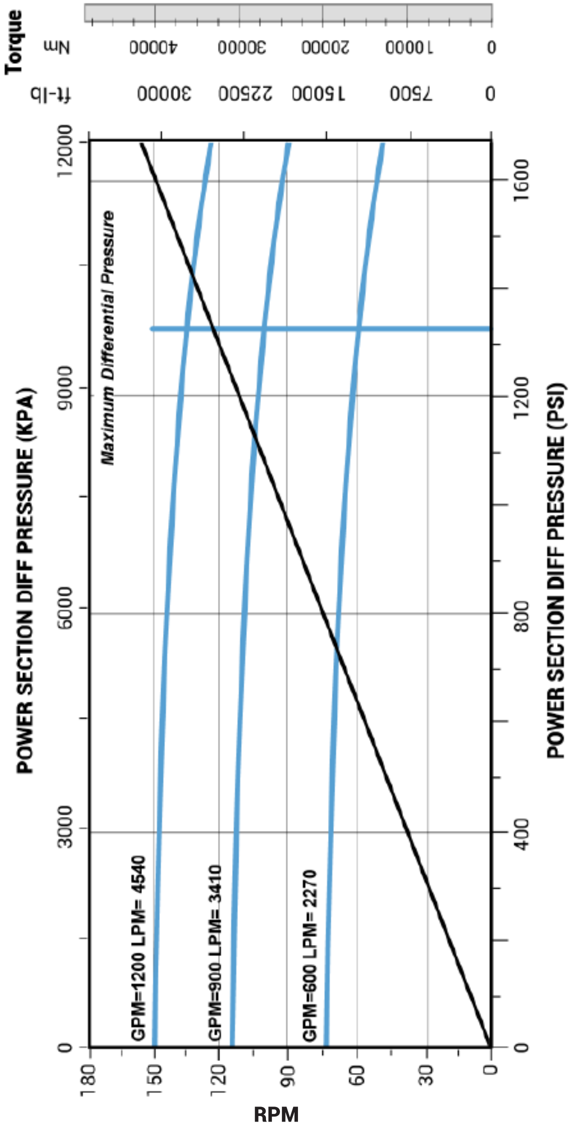
TiTAN22 | 9.15" 7/8 5.7



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 9.15" 7/8 5.7



*(Right) **The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

TiTAN22 | 9.15" 7/8 5.9

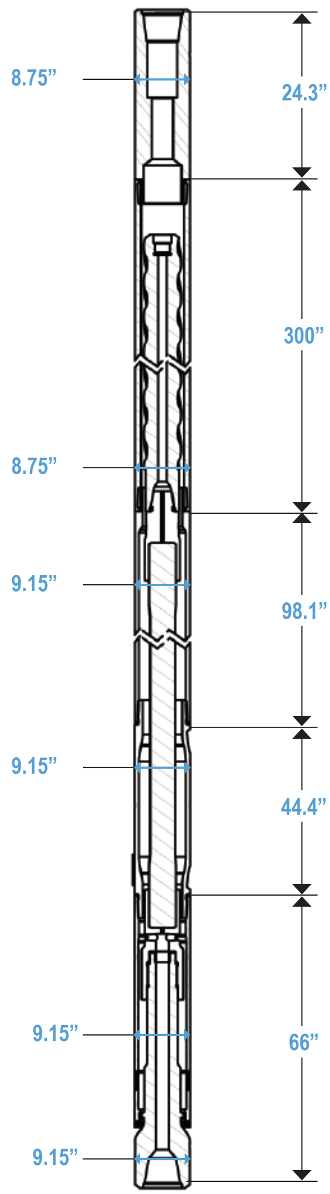
GENERAL SPECIFICATIONS	
OD	9.15 in. (232.41 mm)
Length	44.4 ft (13.53 m)
Recommended Hole Sizes	12 1/4-26 in (311.15-660.40 mm)
Max Bend Angle	1.83°

BEARING SECTION	
Bit to Bend Length	66 in. (1.67 m)
Bit Box Connection	6 5/8 in., 7 5/8 in API Reg. Box
Max WOB	120,000 lbs (53,378 DaN)
Max Overpull for Rerun	100,000 lbs (48,930 DaN)
Overpull to Yield Motor	250,000 lbs (111,205 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	250-900 psi (1,723-6,205 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	7/8
Stages	5.9
Max Differential Pressure	1,390 psi (9,600 kPa)
Stall Differential Pressure	2,190 psi (15,100 kPa)
Torque at Max Diff Pressure	21,870 ft-lbs (29,700 Nm)
Stall Torque	34,440 ft-lbs (46,700 Nm)
Flow Range	400-900 gal/min (1,510-3,410 L/min)
Speed Range	60 - 140 RPM
Speed Ratio	0.15 rev/gal (0.04 rev/L)
Torque Slope	15.77 ft-lb/psi (3.10 Nm/kPa)

GENERAL DIMENSIONS

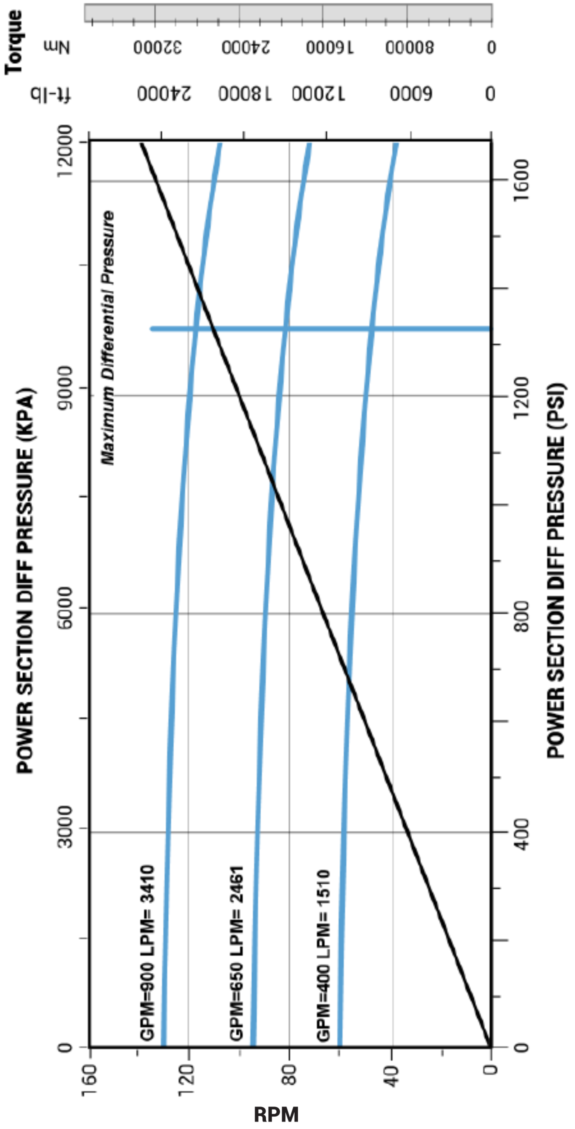
TiTAN22 | 9.15" 7/8 5.9



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 9.15" 7/8 5.9



*(Right) **The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

TiTAN22 | 9.15" 7/8 7.0

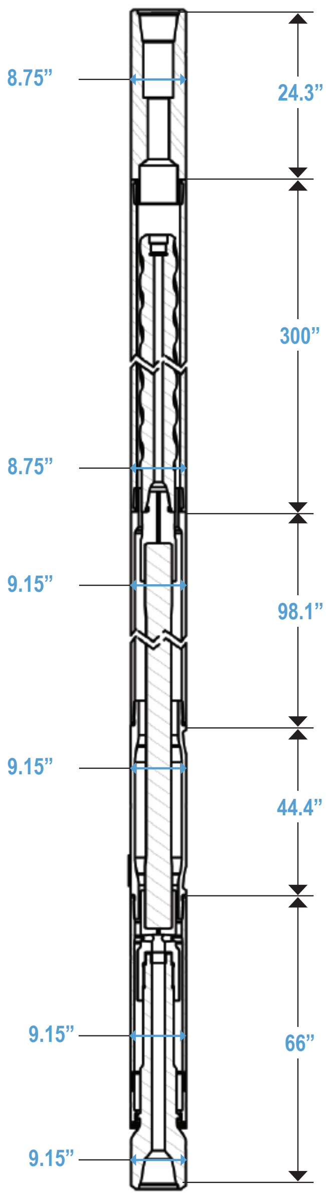
GENERAL SPECIFICATIONS	
OD	9.15 in. (232.41 mm)
Length	44.4 ft (13.53 m)
Recommended Hole Sizes	12 1/4-26 in (311.15-660.40 mm)
Max Bend Angle	1.83°

BEARING SECTION	
Bit to Bend Length	66 in. (1.67 m)
Bit Box Connection	6 5/8 in., 7 5/8 in API Reg. Box
Max WOB	120,000 lbs (53,378 DaN)
Max Overpull for Rerun	100,000 lbs (48,930 DaN)
Overpull to Yield Motor	250,000 lbs (111,205 DaN)
Max Bit Pressure Drop	1,000 psi (6,894 kPa)
Opt Bit Pressure Drop	250-900 psi (1,723-6,205 kPa)
LCM Capability	40 lb nut plug

POWER SECTION	
Lobe Configuration	7/8
Stages	7.0
Max Differential Pressure	1,650 psi (11,376 kPa)
Stall Differential Pressure	2,600 psi (17,926 kPa)
Torque at Max Diff Pressure	25,210 ft-lbs (34,180 Nm)
Stall Torque	39,700 ft-lbs (53,826 Nm)
Flow Range	400-1000 gal/min (1,514-3,785 L/min)
Speed Range	60 - 160 RPM
Speed Ratio	0.15 rev/gal (0.039 rev/L)
Torque Slope	15.32 ft-lb/psi (3.01 Nm/kPa)

GENERAL DIMENSIONS

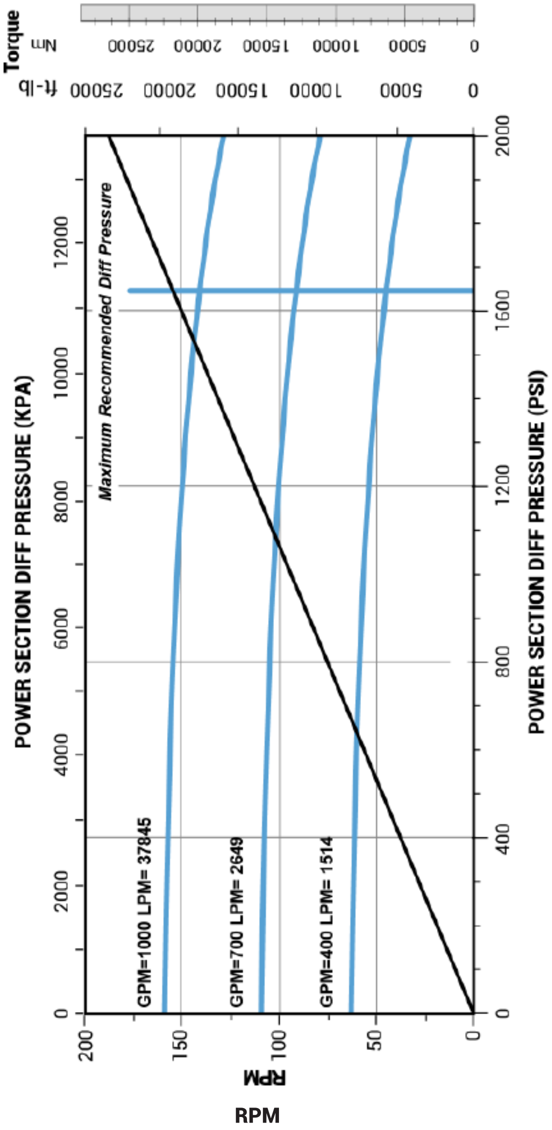
TiTAN22 | 9.15" 7/8 7.0



For fishing diagrams, please contact your SDI Representative.

PERFORMANCE CURVE

TiTAN22 | 9.15" 7/8 7.0



*(Right) **The DLS in the figure represents the local dog-leg.**

For Example: If the motor slides for 10 ft and outputs a 15°/100 ft curve over that 10 ft, the local dog-leg (DLS in the figure) is 15°/100ft. The rotation limits should be adhered to when the bit depth is within +/- 5 ft of the slide length, as well as in the slide length.

APPENDIX

TALON II ADJUSTMENT PROCEDURE

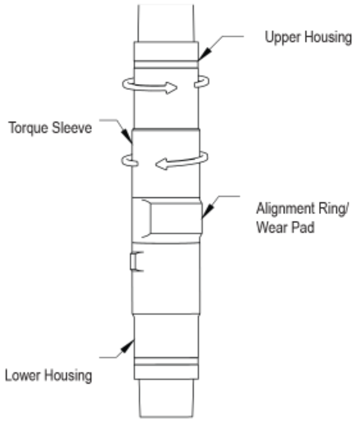


Fig. 1

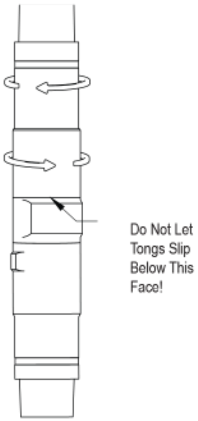


Fig. 2

1. Break Connection
2. Place rig tongs on the Upper Housing and on the Torque Sleeve. Break the connection by applying torque in the direction indicated in Fig. 1
3. Set ABH Angle
4. Holding the Upper Housing stationary, rotate the Lower Housing until the desired angle marks are aligned on the Alignment Ring and the Lower Housing
5. Note: Always use the shortest direction to the required bend angle setting
6. Make-Up Connection
7. Holding the Upper and the Lower Housings stationary, use a chain tong to make-up the Torque Sleeve until it shoulders on the Alignment Ring.
8. Place rig tongs on the Upper Housing and on the Torque Sleeve. Torque connection to recommended value by applying torque in the direction indicated in Fig. 2.

TALON II ABH TORQUE VALUES

Motor Size	Torque ft-lbs	Torque Nm
2-3/8"	1,250	1,694
2-7/8"	2,750	3,728
3-3/4"	5,000	6,779
4-3/4"	9,000	12,202
6-1/4"	19,500	26,438
6-1/2"	26,500	35,929
6-3/4"	28,500	38,640
8"	47,500	64,401
9-5/8"	70,000	94,907

SHOCK AND VIBRATION LIMITS

AXIAL VIBRATION

DD Level	0	1	2	3
RMS (g)	< 2	2 - 4	4 - 6	> 6
Time (hrs)	None	None	6	0.5

LATERAL VIBRATION

DD Level	0	1	2	3
RMS (g)	< 2.5	2.5 - 5	5 - 7.5	> 7.5
Time (hrs)	None	None	6	0.5

STICK SLIP

DD Level	0	1	2	3 - 6
RMS (g)	< 100%	100 - 150%	150 - 200%	> 200%
Time (hrs)	None	None	6	0.5

HOLE SIZE RANGE PER MOTOR SIZE

MOTOR SIZE	RECOMMENDED HOLE SIZE RANGE	
3¾"	4¾" – 5⅞"	121 – 149 mm
4¾"	5⅞" – 7⅞"	149 – 200 mm
6¼"	7⅞" – 8¾"	200 – 222 mm
6½"	7⅞" – 9⅞"	200 – 251 mm
6¾"	8½" – 9⅞"	216 – 251 mm
7¼"	8½" – 9⅞"	216 – 251 mm
8"	9½" – 12½"	241 – 318 mm
9⅝"	12¼" – 26"	311 – 660 mm

PREDICTED BUILD RATE

The following tables predict the average build rate based on the size of the motor, hole size, and the bend angle of the drive shaft housing. Since other factors, such as formation, bit type, WOB, hole gauge, etc. affect the actual build rate, the following numbers should be used as a guide only. Note: the expected build rates are for slick assemblies, and the use of stabilizers will affect the dogleg expectancy.

3¾" Motor												
Bend Angle (Deg)	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
Hole Size	Expected Build Rate (deg/100 ft)											
4¾"	N/A	2.7	3.8	6.1	8.5	11.2	13.5	15.9	18.4	20.8	23.3	26.1
5⅞"	N/A	2.6	3.7	5.5	7.9	10.5	12.8	15.1	17.2	19.9	22.3	25.0

4¾" Motor												
Bend Angle (Deg)	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
Hole Size	Expected Build Rate (deg/100 ft)											
5⅞"	1.8	3.6	5.4	7.2	9.0	10.8	12.5	14.3	17.2	19.6	22.0	24.5
6⅛"	1.7	3.4	5.2	7.0	8.6	10.4	12.0	13.7	16.4	18.8	21.2	23.7
6¼"	1.6	3.3	5.1	6.8	8.4	10.2	11.8	13.4	16.1	18.5	20.8	23.3
6¾"	1.5	3.1	4.7	6.3	7.8	9.4	10.9	12.4	14.7	17.0	19.5	21.8
7⅞"	1.4	2.8	4.2	5.5	6.9	8.3	9.6	11.0	11.6	12.7	15.3	17.4

PREDICTED BUILD RATE (CONTINUED)

6¼" Motor												
Bend Angle (Deg)	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
Hole Size	Expected Build Rate (deg/100 ft)											
7⅞"	N/A	1.2	2.5	4.2	6.0	7.7	9.5	11.2	13.0	14.6	16.5	18.2
8½"	N/A	N/A	1.5	3.2	4.9	6.7	8.4	10.2	11.9	13.7	15.4	17.2
8¾"	N/A	N/A	1.0	2.8	4.5	6.3	8.0	9.8	11.5	13.3	15.0	16.8

6½" and 6¾" Motor												
Bend Angle (Deg)	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
Hole Size	Expected Build Rate (deg/100 ft)											
7⅞" (6½" only)	1.5	2.9	4.3	5.7	7.1	8.5	9.9	11.3	13.2	15.1	17.0	18.9
8½" & 8¾"	1.4	2.8	4.2	5.6	7.0	8.4	9.8	11.2	13.1	15.0	16.9	18.8
9½"	1.2	2.5	3.7	5.0	6.2	7.5	8.7	9.9	11.1	12.3	13.5	14.7
9⅞"	1.2	2.4	3.6	4.8	6.0	7.2	8.4	9.5	10.6	11.7	12.8	13.9

PREDICTED BUILD RATE (CONTINUED)

7¼" Motor												
Bend Angle (Deg)	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
Hole Size	Expected Build Rate (deg/100 ft)											
8½"	N/A	1.5	2.9	4.4	5.9	7.3	8.7	10.1	11.5	13.0	14.4	15.8
9½"	N/A	0.5	1.9	3.3	4.8	6.2	7.6	9.0	10.4	12.0	13.3	14.7
9⅞"	N/A	N/A	1.5	2.9	4.4	5.8	7.2	8.6	10.2	11.6	13.0	14.4

8" Motor												
Bend Angle (Deg)	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
Hole Size	Expected Build Rate (deg/100 ft)											
9½"	N/A	1.3	2.8	4.3	5.7	7.2	8.6	10.1	11.6	13.0	14.5	15.9
9⅞"	N/A	N/A	2.1	3.6	5.0	6.5	8.0	9.4	10.9	12.3	13.8	15.3
12½"	N/A	N/A	N/A	N/A	N/A	1.8	3.2	4.7	6.2	7.6	9.1	10.5

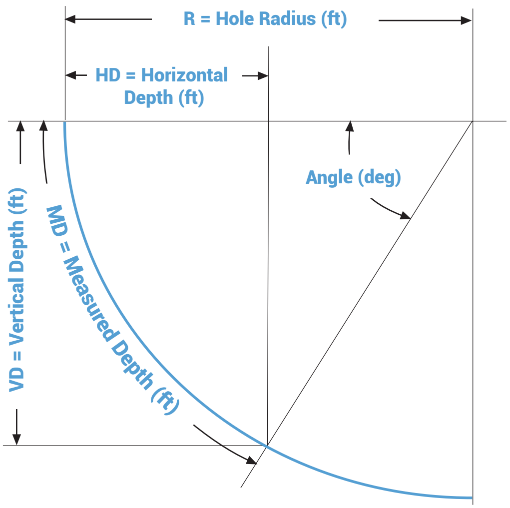
PREDICTED BUILD RATE (CONTINUED)

9⅝" Motor												
Bend Angle (Deg)	0.25	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25	2.50	2.75	3.00
Hole Size	Expected Build Rate (deg/100 ft)											
12¼"	0.8	1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0
14¾"	0.7	1.4	2.1	2.8	3.4	4.1	4.8	5.5	6.1	6.7	7.4	8.1
17½"	0.6	1.1	1.7	2.3	2.8	3.4	4.0	4.5	5.1	5.7	6.2	6.8
22"	0.4	0.8	1.3	1.8	2.2	2.6	3.1	3.5	4.0	4.4	4.9	5.4
26"	0.4	0.7	1.1	1.5	1.9	2.2	2.6	3.0	3.3	3.7	4.1	4.4

HOLE CURVATURE CALCULATION

The following table shows the radius of curvature for different build rates. These numbers are generated by using the Radius Formula.

$$R = MD \div (0.017453 \times Angle)$$
$$VD = R \sin(Angle)$$
$$HD = R\,[1 - \cos(Angle)]$$



Build Rate	Hole Radius		Build Rate	Hole Radius	
°/100 ft	ft	m	°/100 ft	ft	m
2	2,865	873	66	87	27
4	1,432	436	68	84	26
6	955	291	70	82	25
8	716	218	72	80	24
10	573	175	74	77	23
12	477	145	76	75	23
14	409	125	78	73	22
16	358	109	80	72	22
18	318	97	82	70	21
20	286	87	84	68	21
22	260	79	86	67	20
24	239	73	88	65	20
26	220	67	90	64	20
28	205	62	92	62	19
30	191	58	94	61	19
32	179	55	96	60	18
34	169	52	98	58	18
36	159	48	100	57	17
38	151	46	105	55	17
40	143	44	110	52	16
42	136	41	115	50	15
44	130	40	120	48	15
46	125	38	125	46	14
48	119	36	130	44	13
50	115	35	135	42	13
52	110	34	140	41	13
54	100	30	145	40	12
56	102	31	150	38	12
58	99	30	155	37	11
60	95	29	160	36	11
62	92	28	165	35	11
64	90	27	170	34	10

FORMULAS

Horsepower

$$BHP = \frac{P_b \times Q}{1714}$$

BHP = Bit Hydraulic Horsepower (HP)
P_b = Bit Pressure Drop (psi)
Q = Flow Rate (gal/min)

$$MHP = \frac{T \times N}{5252}$$

MHP = Mechanical Horsepower (HP)
T = Torque (ft-lb)
N = Motor RPM

$$AHHP = \frac{P \times Q}{1714}$$

AHHP = Available Hydraulic Horsepower to Motor (HP)
P = Motor Pressure Drop (psi)
Q = Flow Rate (gal/min)

Pressure

$$Pb = \frac{Q^2 \times W}{10856 \times TFA^2}$$

Pb = Bit Pressure Drop (psi)
Q = Flow Rate (gal/min)
W = Mud Weight (lb/gal)
TFA = Total Flow Area (in^2)

$$Ph = 0.052 \times TVD \times W$$

Ph = Hydrostatic Pressure
TVD = Total Vertical Depth (ft)
W = Mud Weight (lb/gal)

$$PNC = \frac{P_{OC} \times W_{New}}{W_{Old}}$$

PNC = New Circulating Pressure Due to Change in Mud Weight
P_{OC} = Old Circulating Pressure (psi)
W_{New} = New Mud Weight (lb/gal)
W_{Old} = Old Mud Weight (lb/gal)

Velocity

$$AV = \frac{0.4085 \times Q}{D_h^2 - D_s^2}$$

AV = Annular Velocity (ft/sec)
Q = Flow Rate (gal/min)
D_h = Hole Diameter (in)
D_S = Drill string OD (in)

$$NV = \frac{0.3209 \times Q}{A}$$

NV = Nozzle Fluid Velocity (ft/sec)
Q = Flow Rate (gal/min)
A = Nozzle Area (in^2)

Air Motor RPM Calculation

$$RPM_{Motor} = RPM_{Foam} + RPM_{Air}$$

$$RPM_{Foam} = (rev/gal) \times (gal/min)_{Foam}$$

$$RPM_{Air} = \frac{[0.21 \times SCFM \times (460 + BHCT) \times (rev/gal)}{P}$$

RPM_{Foam} = Motor RPM due to flow of foam
RPM_{Air} = Motor RPM due to air flow
rev/gal = Derived from motor specification sheets
gal/min_{Foam} = Volumetric flow rate of foam (gal/min)
SCFM = Compressor input flow rate (before pressurizing)
BHCT = Bottom Hole Circulating Temperature (F°)
P = Exit pressure at the compressor (psi)

Other Useful Formulas

$$\text{Hole Area } (in^2) = \frac{3.1416 \times D_h^2}{4}$$

D_h = Hole Diameter (in)

$$BF = \frac{65.50 - W}{65.50}$$

BF = Buoyancy Factor
W = Mud Weight (lb/gal)

$$BHIF = 0.0173\, Q\, (P_b \times W)^{1/2}$$

BHIF = Bit Hydraulic Impact Force (lb)
Pb = Bit Pressure Drop (psi)
W = Mud Weight (lb/gal)

$$PS = \frac{Q}{PDS}$$

- or -

$$PS = \frac{AV \times C}{PDS}$$

PS = Pump Speed (stroke/min)
Q = Flow Rate (gal/min)
PDS = Pump Displacement (gal/stroke)
AV = Annular Velocity (ft/sec)
C = Annular Capacity

MUD WEIGHT

lb/gal	kg/l	lb/ft³	kg/m³	Sp. Gr.	psi/ft	kPa/m
8.3	0.99	62.08	994.43	1.00	0.431	9.75
8.4	1.01	62.83	1,006.44	1.01	0.436	9.86
8.5	1.02	63.58	1,018.45	1.02	0.441	9.98
8.6	1.03	64.33	1,030.47	1.04	0.447	10.11
8.7	1.04	65.08	1,042.48	1.05	0.452	10.22
8.8	1.05	65.82	1,054.34	1.06	0.457	10.34
8.9	1.07	66.57	1,066.35	1.07	0.462	10.45
9.0	1.08	67.32	1,078.36	1.08	0.467	10.56
9.1	1.09	68.07	1,090.38	1.10	0.472	10.68
9.2	1.10	68.82	1,102.39	1.11	0.478	10.81
9.3	1.11	69.56	1,114.24	1.12	0.483	10.93
9.4	1.13	70.31	1,126.26	1.13	0.488	11.04
9.5	1.14	71.06	1,138.27	1.14	0.493	11.15
9.6	1.15	71.81	1,150.29	1.16	0.498	11.27
9.7	1.16	72.56	1,162.30	1.17	0.504	11.40
9.8	1.17	73.30	1,174.15	1.18	0.509	11.51
9.9	1.19	74.05	1,186.17	1.19	0.514	11.63
10.0	1.20	74.80	1,198.18	1.20	0.519	11.74
10.1	1.21	75.55	1,210.19	1.22	0.524	11.85
10.2	1.22	76.30	1,222.21	1.23	0.530	11.99
10.3	1.23	77.04	1,234.06	1.24	0.535	12.10
10.4	1.25	77.79	1,246.08	1.25	0.540	12.22
10.5	1.26	78.54	1,258.09	1.27	0.545	12.33
10.6	1.27	79.29	1,270.10	1.28	0.550	12.44
10.7	1.28	80.04	1,282.12	1.29	0.556	12.58
10.8	1.29	80.78	1,293.97	1.30	0.561	12.69
10.9	1.31	81.53	1,305.99	1.31	0.566	12.80
11.0	1.32	82.28	1,318.00	1.33	0.571	12.92
11.1	1.33	83.03	1,330.01	1.34	0.577	13.05
11.2	1.34	83.78	1,342.03	1.35	0.582	13.17
11.3	1.35	84.52	1,353.88	1.36	0.587	13.28
11.4	1.37	85.27	1,365.89	1.37	0.592	13.39
11.5	1.38	86.02	1,377.91	1.39	0.597	13.50
11.6	1.39	86.77	1,389.92	1.40	0.602	13.62
11.7	1.40	87.52	1,401.94	1.41	0.607	13.73
11.8	1.41	88.26	1,413.79	1.42	0.613	13.87
11.9	1.43	89.01	1,425.80	1.43	0.618	13.98
12.0	1.44	89.76	1,437.82	1.45	0.623	14.09
12.1	1.45	90.51	1,449.83	1.46	0.628	14.21
12.2	1.46	91.26	1,461.84	1.47	0.633	14.32
12.3	1.47	92.00	1,473.70	1.48	0.639	14.45
12.4	1.49	92.75	1,485.71	1.49	0.644	14.57
12.5	1.50	93.50	1,497.73	1.51	0.649	14.68
12.6	1.51	94.25	1,509.74	1.52	0.654	14.79

NOZZLE SELECTION

For proper sizing of the rotor nozzle, refer to the Motor Specification section and obtain the recommended flow rate through the motor at the desired RPM and differential pressure. Subtract this flow rate from the total desired flow rate to obtain the required flow rate through the nozzle (q). Adjust this flow rate for the actual mud weight as follows:

$$\underset{\text{(gal/min)}}{Q} = \underset{\text{(gal/min)}}{q} \times 0.35 \times \sqrt{\underset{\text{(lb/gal)}}{(\text{Mud Weight})}}$$

Using Q and the desired motor differential pressure, determine the nozzle size from the graph below. Use the next smaller nozzle if between sizes.

Example

A 6¾", 4:5, 7.0 stage extended drilling motor is used to drill a well. A 12.5 lb/gal mud at 750 gal/min will be used to complete this well. If the motor is operated at 700 psi of differential pressure, determine if it is necessary to nozzle the rotor. If so, what is the proper nozzle size?

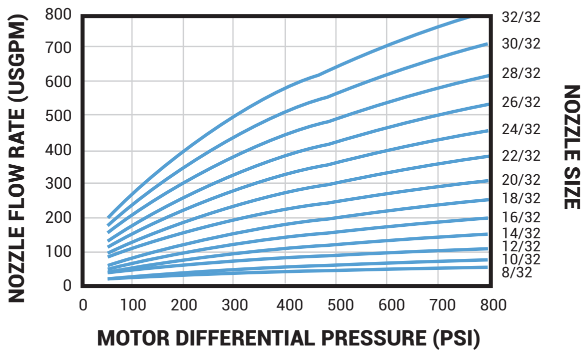
Solution

The maximum allowable flow rate through a 6¾", 4:5, 7.0 stage extended drilling motor is 600 gal/min, as listed in the Motor Specification section. Therefore, the additional 150 gal/min should bypass the power section through the rotor.

To determine the nozzle size, first adjust the flow rate for the actual mud weight:

$$Q = 150 \times 0.35 \times (12.5)^{0.5} = 185.62 \text{ gal/min}$$

The nozzle selection graph shows that pumping 185.62 gal/min at 700 psi differential pressure requires a 16/32 nozzle.



DRILL COLLAR WEIGHT (LB/FT)

OD (in)	Inside Diameter (in)												
	1	1¼	1½	1¾	2	2¼	2½	2 13/16	3	3¼	3½	3¾	4
2⅞	19	18	16										
3	21	20	18										
3⅛	22	22	20										
3¼	26	24	22										
3½	30	29	27										
3¾	35	33	32										
4	40	39	37	35	32	29							
4⅛	43	41	39	37	35	32							
4¼	46	44	42	40	38	35							
4½	51	50	48	46	43	41							
4¾			54	52	50	47	44						
5			61	59	56	53	50						
5¼			68	65	63	60	57						
5½			75	73	70	67	64	60					
5¾			82	80	78	75	72	67	64	60			
6			90	88	85	83	79	75	68	68			
6¼			98	96	94	91	88	83	76	76	72		
6½			107	105	102	99	96	91	85	85	80		
6¾			116	114	111	108	105	100	93	93	89		
7					120	117	114	110	103	103	98	93	94
7¼					130	127	124	119	112	112	108	103	93
7½					139	137	133	129	122	122	117	113	102
7¾					150	147	144	139	132	132	128	123	112
8					160	157	154	150	143	143	138	133	122
8¼					171	168	165	160	154	154	149	144	133
8½					182	179	176	172	165	165	160	155	150
9						203	200	195	188	188	184	179	174
9½						227	224	220	212	212	209	206	198
9¾						240	237	232	225	225	221	216	211
10						254	251	246	239	239	235	230	225
11						310	307	302	295	295	291	286	281
12						371	368	364	357	357	352	347	342

CASING DIMENSIONS AND BIT CLEARANCE

OD (in)	Weight (lb/ft)	Wall	ID	Coupling OD	Drift	Bit Size	Clearance
4½	9.50	0.205	4.090	5.000	3.965	3⅞	0.090
	11.60	0.205	4.000	5.000	3.875	3⅞	0.000
	13.50	0.290	3.920	5.000	3.795	3¾	0.045
	15.10	0.337	3.826	5.000	3.701	3⅝	0.078
5	11.50	0.220	4.560	5.563	4.435	4¼	0.185
	13.00	0.253	4.494	5.563	4.369	4¼	0.119
	15.00	0.296	4.408	5.563	4.283	4¼	0.033
	18.00	0.362	4.276	5.563	4.151	4⅛	0.026
5½	13.00	0.228	5.044	6.050	4.919	4¾	0.169
	14.00	0.244	5.012	6.050	4.887	4¾	0.137
	15.50	0.275	4.950	6.050	4.825	4¾	0.075
	17.00	0.304	4.892	6.050	4.767	4¾	0.017
	20.00	0.361	4.778	6.050	4.653	4⅝	0.028
	23.00	0.415	4.670	6.050	4.545	4½	0.045
6	15.00	0.238	5.524	6.625	5.399	5⅜	0.024
	18.00	0.288	5.425	6.625	5.299	5⅛	0.174
	20.00	0.324	5.352	6.625	5.227	5⅛	0.102
	23.00	0.380	5.240	6.625	5.115	4⅞	0.240
	26.00	0.434	5.132	6.625	5.007	4⅞	0.132
6⅝	17.00	0.245	6.135	7.390	6.010	6	0.010
	20.00	0.288	6.049	7.390	5.924	5⅞	0.049
	24.00	0.352	5.921	7.390	5.769	5¾	0.046
	28.00	0.417	5.791	7.390	5.666	5⅝	0.014
	32.00	0.475	5.675	7.390	5.550	5⅜	0.175
7	17.00	0.231	6.538	7.656	6.413	6⅜	0.038
	20.00	0.272	6.456	7.656	6.331	6¼	0.081
	23.00	0.317	6.366	7.656	6.241	6⅛	0.116
	26.00	0.362	6.276	7.656	6.151	6⅛	0.026
	29.00	0.408	6.184	7.656	6.059	6	0.059
	32.00	0.453	6.094	7.656	5.969	5⅞	0.940
	35.00	0.498	6.004	7.656	5.879	5⅞	0.004
	38.00	0.540	5.920	7.656	5.795	5¾	0.045

CASING DIMENSIONS AND BIT CLEARANCE

OD (in)	Weight (lb/ft)	Wall (in)	ID (in)	Coupling OD (in)	Drift (in)	Bit Size (in)	Clearance (in)
7⅝	20.00	0.250	7.125	8.500	7.000	6¾	0.250
	24.00	0.300	7.025	8.500	6.900	6¾	0.150
	26.40	0.328	6.969	8.500	6.844	6¾	0.094
	29.70	0.375	6.875	8.500	6.750	6¾	0.000
	33.70	0.430	6.765	8.500	6.640	6⅝	0.015
	39.00	0.500	6.625	8.500	6.500	6⅜	0.125
8⅝	24.00	0.264	8.097	9.625	7.972	7⅞	0.097
	28.00	0.304	8.017	9.625	7.892	7⅞	0.017
	32.00	0.352	7.921	9.625	7.796	7¾	0.046
	36.00	0.400	7.825	9.625	7.700	7⅝	0.075
	40.00	0.450	7.725	9.625	7.600	7⅜	0.225
	44.00	0.500	7.625	9.625	7.500	7⅜	0.125
	49.00	0.557	7.511	9.625	7.386	7⅜	0.011
9⅝	29.30	0.281	9.063	10.625	8.907	8¾	0.157
	32.30	0.312	9.001	10.625	8.845	8¾	0.095
	36.00	0.352	8.921	10.625	8.765	8¾	0.015
	40.00	0.395	8.835	10.625	8.697	8⅝	0.072
	43.50	0.435	8.755	10.625	8.599	8½	0.099
	47.00	0.472	8.681	10.625	8.525	8½	0.025
	53.50	0.545	8.535	10.625	8.379	8⅜	0.004
10¾	32.75	0.279	10.192	11.750	10.036	9⅞	0.161
	40.50	0.350	10.050	11.750	9.894	9⅞	0.019
	45.50	0.400	9.920	11.750	9.794	9¾	0.044
	51.00	0.450	9.850	11.750	9.694	9⅝	0.069
	55.50	0.495	9.760	11.750	9.604	9	0.630
	60.70	0.545	9.660	11.750	9.504	9	0.504
	65.70	0.595	9.560	11.750	9.404	9	0.404
11¾	38.00	0.300	11.150	12.750	10.994	10⅝	0.369
	42.00	0.333	11.084	12.750	10.928	10⅝	0.303
	47.00	0.375	11.000	12.750	10.844	10⅝	0.219
	54.00	0.435	10.880	12.750	10.724	10⅝	0.099
	60.00	0.489	10.772	12.750	10.616	9⅞	0.741

CASING DIMENSIONS AND BIT CLEARANCE

OD (in)	Weight (lb/ft)	Wall (in)	ID (in)	Coupling OD (in)	Drift (in)	Bit Size (in)	Clearance (in)
13⅜	48.00	0.330	12.715	14.375	12.559	12¼	0.309
	54.50	0.380	12.615	14.375	12.459	12¼	0.209
	61.00	0.430	12.515	14.375	12.359	12¼	0.109
	68.00	0.480	12.415	14.375	12.259	12¼	0.009
	72.00	0.514	12.374	14.375	12.191	10	2.191
16	55.00	0.312	15.375	17.000	15.188	15	0.188
	65.00	0.375	15.250	17.000	15.062	15	0.062
	75.00	0.438	15.125	17.000	14.938	14¾	0.188
	84.00	0.495	15.010	17.000	14.823	14¾	0.073
20	94.00	0.438	19.124	21.000	18.938	17½	1.436

RECOMMENDED MINIMUM MAKE-UP TORQUE

Protective Sleeve & Near Bit Stabilizer Make-up Torque Values

Tool Size	Torque ft-lbs	Torque Nm
3¾"	6,500	8,813
4¾"	11,000	14,914
6¼"	17,000	23,049
6½"	26,500	35,929
6¾"	26,500	35,929
7¼"	N/A	N/A
8"	29,000	39,319
9⅝"	44,000	59,656

RECOMMENDED MINIMUM MAKE-UP TORQUE (FT-LBS)

Connection Type	OD (in)	Bore of Drill Collars (in)											
		1	1¼	1½	1¾	2	2¼	2½	2 13/16	3	3¼	3½	3¾
API N.C. 23	3	2,500	2,500	2,500									
	3⅛	3,300	3,300	2,600									
	3¼	4,000	3,400	2,600									
2⅞" P.A.C.	3		3,800	3,800	2,900								
	3⅛		4,900	4,200	2,900								
	3¼		5,200	4,200	2,900								
2⅞" AM O.H.	3⅞					4,450*							
2⅞" AM. O.H. Light weight	3¾					2,850*							
2⅞" PH-6	3½					3,500*							
2⅞" 533 HYDRIL	3⅛					2,200*							
2⅜" API I.F., API N.C. 26	3½		4,600	4,600	3,700								
2⅞" Slim Hole	3¾		5,500	4,700	3,700								
2⅞" XHOLE	3¾		4,100	4,100	4,100								
3½" Dbl. Streamline	3⅞		5,300	5,300	5,300								
2⅞" Mod. Open	4⅛		8,000	8,000	7,400								
API N.C. 35	4½				8,900	8,900	8,900	7,400					
	4¾				12,100	10,800	9,200	7,400					
	5				12,100	10,800	9,200	7,400					

Note: The torque values are based on the minimum material yield strength of 120 kpsi. ID of 2" = 2.2.

RECOMMENDED MINIMUM MAKE-UP TORQUE (FT-LBS)

Connection Type	OD (in)	Bore of Drill Collars (in)											
		1	1¼	1½	1¾	2	2¼	2½	2 13/16	3	3¼	3½	3¾
2⅞" API I.F. API N.C. 31 3½" Slim Hole	3⅞		4,600	4,600	4,600	4,600							
	4⅛		7,300	7,300	7,300	6,800							
	4¼		8,800	8,800	8,100	6,800							
	4½		10,000	9,300	8,100	6,800							
3½" XHOLE 4" Slim Hole 3½" Mod. Open	4¼				5,100	5,100	5,100	5,100					
	4½				8,400	8,400	8,400	8,200					
	4¾				11,900	11,700	10,000	8,200					
	5				13,200	11,700	10,000	8,200					
	5¼				13,200	11,700	10,000	8,200					
3½" API I.F. API N.C. 38 4½" Slim Hole	4¾				9,900	9,900	9,900	9,900	8,300				
	5				13,800	13,800	12,800	10,900	8,300				
	5¼				16,000	14,600	12,800	10,900	8,300				
	5½				16,000	14,600	12,800	10,900	8,300				
3½" H-90	4¾				8,700	8,700	8,700	8,700	8,700				
	5				12,700	12,700	12,700	12,700	10,400				
	5¼				16,900	16,700	15,000	13,100	10,400				
	5½				18,500	16,700	15,000	13,100	10,400				

Note: The torque values are based on the minimum material yield strength of 120 kpsi

RECOMMENDED MINIMUM MAKE-UP TORQUE (FT-LBS)

Connection Type	OD (in)	Bore of Drill Collars (in)											
		1	1¼	1½	1¾	2	2¼	2½	2¹³⁄₁₆	3	3¼	3½	3¾
4" Full Hole API N.C. 40 4" Mod. Open 4½" Dbl. Streamline	5				10,800	10,800	10,800	10,800	10,800				
	5¼				15,100	15,100	15,100	14,800	12,100				
	5½				19,700	18,600	16,900	14,800	12,100				
	5¾				20,400	18,600	16,900	14,800	12,100				
	6				20,400	18,600	16,900	14,800	12,100				
4" H-90	5¼					12,500	12,500	12,500	12,500				
	5½					17,300	17,300	17,300	16,500				
	5¾					22,300	21,500	19,400	16,500				
	6					23,500	21,500	19,400	16,500				
	6¼					23,500	21,500	19,400	16,500				
4½" API Regular	5½					15,400	15,400	15,400	15,400				
	5¾					20,300	20,300	19,400	16,200				
	6					23,400	21,600	19,400	16,200				
	6¼					23,400	21,600	19,400	16,200				
API N.C. 44	5¾					20,600	20,600	20,600	18,000				
	6					25,000	23,300	21,200	18,000				
	6¼					25,000	23,300	21,200	18,000				
	6½					25,000	23,300	21,200	18,000				

Note: The torque values are based on the minimum material yield strength of 120 kpsi

RECOMMENDED MINIMUM MAKE-UP TORQUE (FT-LBS)

Connection Type	OD (in)	Bore of Drill Collars (in)											
		1	1¼	1½	1¾	2	2¼	2½	2¹³⁄₁₆	3	3¼	3½	3¾
4½" API Full Hole	5½					12,900	12,900	12,900	12,900	12,900			
	5¾					17,900	17,900	17,900	17,900	17,700			
	6					23,300	23,300	22,800	19,800	17,700			
	6¼					27,000	25,000	22,800	19,800	17,700			
	6½					27,000	25,000	22,800	19,800	17,700			
4½" X-Hole API N.C. 46 4½" Mod. Open 4" API I.F. 5" Dbl. Streamline	5¾						17,600	17,600	17,600	17,600			
	6						23,200	23,200	22,200	20,200			
	6¼						28,000	25,500	22,200	20,200			
	6½						28,000	25,500	22,200	20,200			
	6¾						28,000	25,500	22,200	20,200			
4½" H-90	5¾						17,600	17,600	17,600	17,600			
	6						23,400	23,400	23,000	21,000			
	6¼						28,500	26,000	23,000	21,000			
	6½						28,500	26,000	23,000	21,000			
	6¾						28,500	26,000	23,000	21,000			
5" H-90	6¼						25,000	25,000	25,000	25,000			
	6½						31,500	31,500	29,500	27,000			
	6¾						35,000	33,000	29,500	27,000			
	7						35,000	33,000	29,500	27,000			

Note: The torque values are based on the minimum material yield strength of 120 kpsi

RECOMMENDED MINIMUM MAKE-UP TORQUE (FT-LBS)

Connection Type	OD (in)	Bore of Drill Collars (in)											
		1	1¼	1½	1¾	2	2¼	2½	2 13/16	3	3¼	3½	3¾
5½" H-90	6¾						34,000	34,000	34,000	34,000			
	7						41,500	40,000	36,500	34,000			
	7¼						42,500	40,000	36,500	34,000			
	7½						42,500	40,000	36,500	34,000			
5½" API Regular	6¾						31,500	31,500	31,500	31,500			
	7						39,000	39,000	36,000	33,500			
	7¼						42,000	39,500	36,000	33,500			
	7½						42,000	39,500	36,000	33,500			
4½" API I.F. API N.C. 50 5" Extra Hole 5" Mod. Open 5½" Dbl. Streamline	6¼						22,800	22,800	22,800	22,800	22,800		
	6½						29,500	29,500	29,500	29,500	26,500		
	6¾						36,000	35,500	32,000	30,000	26,500		
	7						38,000	35,500	32,000	30,000	26,500		
	7¼						38,000	35,500	32,000	30,000	26,500		
5½" API Full Hole	7							32,500	32,500	32,500	32,500		
	7¼							40,500	40,500	40,500	40,500		
	7½							49,000	47,000	45,000	41,500		
	7¾							51,000	47,000	45,000	41,500		

Note: The torque values are based on the minimum material yield strength of 120 kpsi

RECOMMENDED MINIMUM MAKE-UP TORQUE (FT-LBS)

Connection Type	OD (in)	Bore of Drill Collars (in)											
		1	1¼	1½	1¾	2	2¼	2½	2 13/16	3	3¼	3½	3¾
API N.C. 56	7¼							40,000	40,000	40,000	40,000		
	7½							48,500	48,000	45,000	42,000		
	7¾							51,000	48,000	45,000	42,000		
	8							51,000	48,000	45,000	42,000		
6⅝" API Regular	7½							46,000	46,000	46,000	46,000		
	7¾							55,000	53,000	50,000	47,000		
	8							57,000	53,000	50,000	47,000		
	8¼							57,000	53,000	50,000	47,000		
6⅝" H-90	7½							46,000	46,000	46,000	46,000		
	7¾							55,000	55,000	53,000	49,500		
	8							59,500	56,000	53,000	49,500		
	8¼							59,500	56,000	53,000	49,500		
API N.C. 61	8							54,000	54,000	54,000	54,000		
	8¼							64,000	64,000	64,000	61,000		
	8½							72,000	68,000	65,000	61,000		
	8¾							72,000	68,000	65,000	61,000		
	9							72,000	68,000	65,000	61,000		

Note: The torque values are based on the minimum material yield strength of 120 kpsi

RECOMMENDED MINIMUM MAKE-UP TORQUE (FT-LBS)

Connection Type	OD (in)	Bore of Drill Collars (in)											
		1	1¼	1½	1¾	2	2¼	2½	2 13/16	3	3¼	3½	3¾
5½" API I.F.	8							56,000	56,000	56,000	56,000	56,000	
	8¼							66,000	66,000	66,000	63,000	59,000	
	8½							74,000	70,000	67,000	63,000	59,000	
	8¾							74,000	70,000	67,000	63,000	59,000	
	9							74,000	70,000	67,000	63,000	59,000	
	9¼							74,000	70,000	67,000	63,000	59,000	
6⅝" API Full Hole	8½								67,000	67,000	67,000	67,000	66,500
	8¾								78,000	78,000	76,000	72,000	66,500
	9								83,000	80,000	76,000	72,000	66,500
	9¼								83,000	80,000	76,000	72,000	66,500
	9½								83,000	80,000	76,000	72,000	66,500
API N.C. 70	9								75,000	75,000	75,000	75,000	75,000
	9¼								88,000	88,000	88,000	88,000	88,000
	9½								101,000	101,000	100,000	95,000	90,000
	9¾								107,000	105,000	100,000	95,000	90,000
	10								107,000	105,000	100,000	95,000	90,000
	10¼								107,000	105,000	100,000	95,000	90,000

Note: The torque values are based on the minimum material yield strength of 120 kpsi

RECOMMENDED MINIMUM MAKE-UP TORQUE (FT-LBS)

Connection Type	OD (in)	Bore of Drill Collars (in)											
		1	1¼	1½	1¾	2	2¼	2½	2 13/16	3	3¼	3½	3¾
API N.C. 77	10									107,000	107,000	107,000	107,000
	10¼									122,000	122,000	122,000	122,000
	10½									138,000	138,000	133,000	128,000
	10¾									143,000	138,000	133,000	128,000
	11									143,000	138,000	133,000	128,000
7" H-90	8								53,000	53,000	53,000	53,000	
	8¼								63,000	63,000	63,000	60,500	
	8½								71,500	68,500	65,000	60,500	
7⅝" API Regular	8½									60,000	60,000	60,000	60,000
	8¾									71,000	71,000	71,000	71,000
	9									83,000	83,000	79,000	74,000
	9¼									88,000	83,000	79,000	74,000
	9½									88,000	83,000	79,000	74,000

Note: The torque values are based on the minimum material yield strength of 120 kpsi

RECOMMENDED MINIMUM MAKE-UP TORQUE (FT-LBS)

Connection Type	OD (in)	Bore of Drill Collars (in)											
		1	1¼	1½	1¾	2	2¼	2½	2¹³⁄₁₆	3	3¼	3½	3¾
7⅝" H-90	9									72,000	72,000	72,000	72,000
	9¼									85,500	85,500	85,500	85,500
	9½									98,000	98,000	98,000	95,500
8⅝" API Regular	10									108,000	108,000	108,000	108,000
	10¼									123,000	123,000	123,000	123,000
	10½									139,000	134,000	129,000	123,000
8⅝" H-90	10¼									112,500	112,500	112,500	112,500
	10½									128,500	128,500	128,500	128,500

Note: The torque values are based on the minimum material yield strength of 120 kpsi

ROTARY SHOULDER CONNECTION INTERCHANGE LIST

Common Name	Size (in)	Same As or Interchanges With
Internal Flush (IF)	2⅜	2⅞ in Slim Hole NC 26
	2⅞	3½ in Slim Hole NC 31
	3½	4½ in Slim Hole NC 38
	4	4½ in Extra Hole NC 46
	4½	5 in Extra Hole NC 50 or 5½ in Double Streamline
Full Hole (FH)	4	4½ in Double Streamline NC 40
Extra Hole (XH) or (EH)	2⅞	3½ in Double Streamline
	3½	4 in Slim Hole or 4½ in External Flush
	4½	4 in Internal Flush NC 46
	5	4½ in Internal Flush NC 50 or 5½ in Double Streamline
Slim Hole (SH)	2⅞	2⅜ in Internal Flush NC 26
	3½	2⅞ in Internal Flush NC 31
	4	3½ in Extra Hole or 4½ in External Flush
	4½	3½ in Internal Flush NC 38
Double Streamline (DSL)	3½	2⅞ in Extra Hole
	4½	4 in. Full Hole NC 31
	5½	4½ in Internal Flush or 5 in Extra Hole NC 50
Numbered Connections (NC)	26	2⅜ in Internal flush or 2⅞ in Slim Hole
	31	2⅞ in Internal Flush or 3½ in Slim Hole
	38	3½ in Internal Flush or 4½ in Slim Hole
	40	4 in Full Hole or 4½ in Double Streamline
	46	4 in Internal Flush or 4½ in Extra Hole
	50	4½ in Internal Flush or 5 in Extra Hole or 5½ in Double Streamline
External Flush (EF)	4½	4 in Slim Hole or 3½ in Extra Hole

HEAVY-WALL DRILL PIPE PROPERTIES

Standard

Nominal Size (in)	Pipe ID (in)	Nominal Weight (lb/ft)	Tool Joint Connection (in)
3½″	2.063	25.3	3.5 IF (NC 38)
4″	2.563	29.7	4 FH (NC 40)
4½″	2.75	41.0	4 IF (NC 46)
5″	3.0	48.5	4.5 IF (NC 50)

Spiral-Wate™

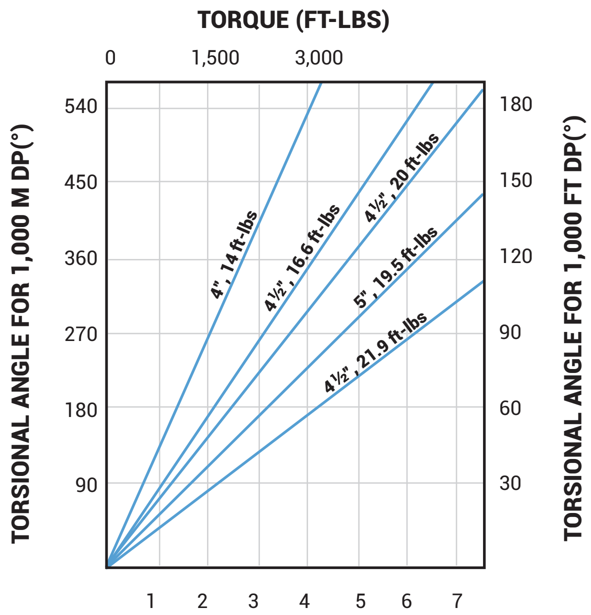
Nominal Size (in)	Pipe ID (in)	Nominal Weight (lb/ft)	Tool Joint Connection (in)
3½″	2.25	26.7	3.5 IF (NC 38)
4″	2.563	32.7	4 FH (NC 40)
4½″	2.75	42.6	4 IF (NC 46)
5″	3.0	53.6	4.5 IF (NC 50)
5½″	4.0	50.7	5 FH
6⅞″	5.0	57.0	6.625 FH

TORSIONAL ANGLE OF DRILL PIPE

The effective angle of torsion is calculated by:

$$\text{Torsional Angle} = \frac{(\text{Angle for 1,000 ft}) \times (\text{Length of } D_P/\text{ft})}{1{,}000}$$

***Calculation does not include wall friction*



CONVERSION FACTORS

SI Prefixes

Multiplying Factor	Prefix	Symbol
1,000,000 = 10^6	mega	M
1,000 = 10^3	kilo	k
100 = 10^2	hecto	h
10 = 10^1	deca	da
0.1 = 10^{-1}	deci	d
0.01 = 10^{-2}	centi	c
0.001 = 10^{-3}	milli	m
0.000,001 = 10^{-6}	micro	μ

Units	Multiply By	To Obtain
ac	43560	ft^2
ac	4047	m^2
ac	0.001562	mi^2
atm	33.94	ft of water (60ºF)
atm	14.7	lb/in^2
atm	1.013×10^5	pascals
atm	1.033	kg/cm^2
bbl (British, dry)	5.78	ft^3
bbl (British, dry)	0.1637	m^3
bbl (British, dry)	36	gal (British)
bbl, cement	170.6	kg
bbl, cement	376	lb (cement)
bbl, oil	42	gal (U.S.)
bbl (U.S., liquid)	4.211	ft^3
bbl (U.S., liquid)	0.1192	m^3
bbl (U.S., liquid)	31.5	gal (U.S.)
bbl/min	42	gal/min
bbl/day	0.02917	gal/min
cm	0.3937	in
cm	3.281×10^{-2}	ft
cm^3	3.531×10^{-5}	ft^3
deg (angle)	60	min
deg (angle)	0.01745	rad
deg (angle)	3600	s
deg/s	0.1667	rpm
deg/s	2.778×10^{-3}	rev/s
ft	12	in
ft	0.3048	m
ft	1.89394×10^{-4}	mi

Units	Multiply By	To Obtain
ft^2	0.0929	m^2
ft^3	1728	in^3
ft^3	0.02832	m^3
ft^3	7.481	gal (U.S.)
ft^3	28.32	liters
ft^3 of water (60ºF)	62.37	lb
ft^3/min	4.72×10^{-4}	m^3/s
ft^3/min	0.1247	gal/s
ft^3/min	0.472	liters/s
ft^3/s	448.83	gal/min
ft^3 - atm	2116.3	ft-lb
ft-lb	1.286×10^{-3}	Btu
ft-lb	0.1383	kg/m
ft-lb	1.355818	Nm
ft/min	0.508	cm/s
ft/min	0.01667	ft/s
ft/min	0.01829	km/hr
ft/min	0.3048	m/min
ft/min	0.01136	mi/hr
ft-lb/min	0.01667	ft-lb/s
ft-lb/min	2.26×10^{-5}	kW
ft-lb/s	1.356×10^{-3}	kW
ft-lb/s	1.818×10^{-3}	hp
g	0.001	kg
gal (British)	1.20094	gal (U.S.)
gal	3785	cm^3
gal	0.1337	ft^3
gal	231	in^3
gal	3.785	liters
gal/min	2.228×10^{-3}	ft^3/s
gal/min	3.785	liters/min
$g\text{-}cm^2$	3.4172×10^{-4}	$lb\text{-}in^2$
hp	0.7457	kW
in	25.4	mm
in^2	645.2	mm^2
in^2	6.452	cm^2
in^2	6.944×10^{-3}	ft^2
in^3	1.639×10^{-5}	m^3
in^3	5.787×10^{-4}	ft^3
in^3	4.329×10^{-3}	gal
in^3	0.01639	liters
in^3	1000	liters

Units	Multiply By	To Obtain
kg	2.2046	lb
kg-m	7.233	ft-lb
kg/m³	0.06243	lb/ft³
kg/m	0.672	lb/ft
kW	4.462×10^{4}	ft-lb/min
kW-hr	2.655×10^{6}	ft-lb
lb	4.45×10^{5}	dynes
lb	4.448	newtons
lb	4.535×10^{-4}	tons (metric)
lb/ft³	16.02	kg/m³
lb/ft³	5.787×10^{-4}	lb/in³
lb/ft²	4.882	kg/m²
lb/ft²	6.945×10^{-3}	lb/in²
lb/gal	7.48	lb/ft³
lb/gal	0.12	specific gravity
lb/gal	0.1198	g/cm³
lb/in²	6.894757	kPa
liter	0.03531	ft³
liter	0.001	m³
liter	0.2642	gal
m	3.2808	ft
m²	10.764	ft²
m³	264.2	gal
m³/s	15850	gal/min
m³/s	60000	liters/min
mi²	2.788×10^{7}	ft²
mi²	2.59	km²
rad	57.3	deg
rad/s	0.1592	rev/s
rad/s	9.549	rpm
tons (metric)	1000	kg
w	0.7376	ft-lb/s
w	1.341×10^{-3}	hp
yds	3	ft
yds	0.9144	m

Temperature Conversion	
Fahrenheit (ºF) to Celsius (ºC)	(5/9) x (ºF - 32)
Celsius (ºC) to Fahrenheit (ºF)	1.8 x ºC + 32

BIT OFF-BOTTOM
TROUBLESHOOTING CHART

Primary Indication	Possible Cause	Subsequent Mode of Action
Drop in circulating pressure to lower than calculated	Lost circulation	Lost circulation procedure
	Drill string washout	Pull out for check
	Open dump valve	Stop pumps, restart with increased flow, pull string if not corrected
Circulating pressure higher than calculated	Plugged motor or bit	Stop pumps, restart and vary flow rate, then reciprocate string
	Bit side-loading	Drill ahead carefully to relax tool assembly

DRILLING WITH MOTOR ONLY
TROUBLESHOOTING CHART

Primary Indication	Secondary Indication	Possible Cause	Subsequent Mode of Action
No penetration	Drill Pipe Pressure (DPP) higher than maximum	Motor stall	Pull off-bottom to restart motor and apply WOB carefully
DPP rises higher than maximum calculated	No penetration	Motor stall	Pull off-bottom to restart motor and apply WOB carefully
ROP decreases	DPP rises – WOB normal	Broken or worn cutters. Bit "ringing"	Calculate cost-per-foot and either continue or pull out
	DPP falls – WOB normal	Hard formation or stabilizers hanging up	Continue with caution but if unsatisfactory, pull the bit
	DPP rises – Fails to respond to increased WOB	Bit balling	Lift off-bottom, reciprocate, then wash away balling material
	Slow fall in DPP	Bit is wearing	Calculate cost-per-foot and either continue or pull out
	DPP fluctuates	Assembly bouncing junk in hole	Attempt to wash away junk, then fish if unsuccessful
Sudden rise in ROP	DPP rises – WOB normal	Softer formation encountered	Pull off-bottom, reassess angular reactive torque, then continue drilling using recalculated parameters
	Tool Face Heading (TFH) turns to left		

DRILLING WITH MOTOR AND ROTARY
TROUBLESHOOTING CHART

ROP	SPP	WOB	Rotary Torque	Possible Cause	Subsequent Mode of Action
Falls	Falls	Normal	Normal	Open dump valve or wash out	Stop pumps, restart, vary flow rate, then pull string if not corrected
			Rises	Stabilizers reaming	Continue with caution but if unsatisfactory, pull bit
			Falls	Harder formation encountered	Optimize ROP, then continue drilling
	Rises	Normal	Falls	Bit balling	Lift off-bottom, then reciprocate, wash away balling material
				Bit ringing	Calculate cost-per-foot and either continue or pull bit
			Rises	Motor stall	Immediately stop rotary, then pull off-bottom and restart cautiously
	Fluctuates	Normal	Fluctuates	Junk in hole, bit cones locking	Attempt to wash away junk, then fish if necessary
Normal	Falls	Normal	Normal	Drill string wash-out	Pull out for check
	Rises	Normal	Normal	Plugged motor or bit	Stop pump, restart and vary pressure, reciprocate string
Rises	Rises	Normal	Rises	Softer formation encountered	Optimize ROP, then continue drilling

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