PowerDrive Orbit & X6
Quick Operations Guide

Revision 1.4
6 March 2020

This document should serve as a basic guide for Extreme Equipment Rental clients for planning and executing a successful PowerDrive Orbit or X6 job in North America.

Contents

1 Job Planning

1.1 BHA Design

1.1.1 Stabilization

All PowerDrive BHA's should have at least 2 stabilizers. The first stabilizer should be located on the PD control collar or directly behind it. The 2^{nd} should be 30-40 feet behind the first. Proper stabilizer placement ensures optimal steering response and minimizes shock & vibration damage. Depending on the BHA design, a 3^{rd} stabilizer may be added another 30-40 feet behind the 2^{nd} stabilizer. This may aid in shock & vibration mitigation on the MWD but will have minimal effect on steering.

The first stabilizer should be 1/8" Under-gauge from the hole-size. The additional stabilizers may be 1/8" or ¼" Under-gauge depending on the application.

Stabilizers should have spiral wrap, short gauge, and long tapers. A good rule of thumb is to aim for a gauge length that is 50% of the hole-size and 60 degree taper. This design optimizes steerability while preventing stabilizer jamming.

Roller Reamers may be used in place of stabilizers to reduce torque and stick-slip. Do not use eccentric reamers or hole-openers in place of stabilizers.

1.1.2 Motor Selection

Bearing sections must be fixed-straight, not adjustable dialed to zero. Adjustable motors, even when dialed to zero bend, have an offset that can initiate vibration.

Consider the PowerDrive RPM specification (220 for X6, 350 for Orbit) when choosing rev/gallon of the power section. Exceeding the RPM specification will lead to reduced dogleg and tool damage.

1.1.3 Bit Selection

Extremely aggressive bits can cause stick-slip and whirl. These dynamics may lead to tool damage, reduced dogleg, and lower ROP.

Tapering or under-cutting the back end of the gauge pad is recommended to maximize dogleg and prevent excessive torque or stick-slip. This also allows for longer gauge lengths in tangent/horizontal sections to improve stability.

"Active Gauge" bits should be avoided as the negative effects outweigh any benefits.

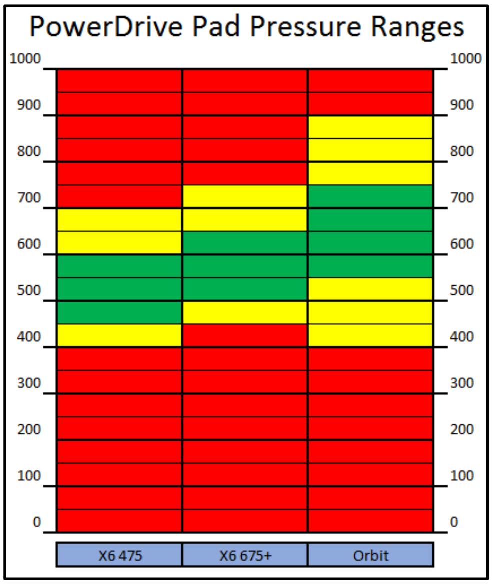
Depth of cut management features can aid in minimizing stick-slip but avoid placing them on the shoulder of the bit as this may reduce dogleg significantly.

1.1.4 Additional Considerations

Flex Ponies and Collars should generally be avoided, especially in tangents or horizontals, as they increase the odds of shock and vibration damage. A short Flex Pony directly on top of the PD tool will increase the maximum dogleg by 1-2 degrees but should only be used if truly necessary.

1.2 Hydraulics

1.2.1 Optimizing Hydraulics



The Bias Unit uses the mud flow to activate the steering pistons or pads, exerting a side force on the bit. This operational principle requires a pressure drop between the steering unit and the annulus, which can be achieved by a combination of bit nozzling and a flow restrictor inside the steering unit.

The amount of steering force is proportional to the differential pressure across the pistons or pads. Insufficient piston or pad pressure will result in a reduced BHA steering response, and excessive pressure will increase the risk of causing damage to the tool. The following table should be used when optimizing hydraulics.

Recent US Land experience has shown that excessive pressure with Orbit may also lead to reduced steering response by breaking down the formation rather than pushing off of it. For this reason, it is advised to stay in the green or lower-yellow regions unless local experience suggests that running in the upper-yellow range is truly necessary.

1.2.2 Pressure Calculator on the PowerDrive App

The Pressure Calculator on the PowerDrive App should be used during the planning stages and on the rig for real-time hydraulics adjustments. PD² is the old hydraulic calculation method, it requires installing a separate program on a personal computer. The PowerDrive App has the most accurate output and is the preferred method for calculating PowerDrive hydraulics.

When planning an Orbit job, it is safe to use 0.08 mm as a default ball-sleeve radial gap. But the DD's must be sure to re-run hydraulics once they know the gaps for their specific tool. These can be found on the first page of the PD Outgoing Systems Test (OST) paperwork. Entering incorrect ball-sleeve gaps can lead to inaccurate pad pressures.

Request the calculated bearing loss from the motor vendor for all mud-lubed or sealed bearing motors. Be sure the motor vendor considers the mud properties and higher than normal pressure drop below the motor when providing their estimate. These should be entered into the PowerDrive App for accurate pad pressure calculations. "Sealed" Bearings may have more leakage than mud-lubed bearings. It is suggested to request new radial bearings when ordering motors to avoid excessive leakage. Some motors may leak over 25% fluid and still meet the vendor's re-use criteria.

The PowerDrive App is color coded as shown in the top image to turn green when the pressure drop is within the optimal range. The pressure drop will increase/decrease as the nozzle sizes are changed or a flow restrictor is added. **Important: The number of nozzles and their sizes must be reflected on the downhole setup of the bit.**

The Pressure Drop Chart can be utilized while drilling to update the Real-Time Pressure Drop across the PowerDrive. This is critical as the Mud Weight, Pump Rate and Total Leakage change during a run. It is important to maintain a Pressure Drop in the green zone as these parameters change.

1.2.3 Flow Restrictor Use and Availability

If the desired pad pressure cannot be achieved by nozzling the bit alone, a flow restrictor can be used. A PowerDrive Flow Restrictor provides additional pressure drop at the RSS tool to increase pad pressure and force without affecting the bit TFA. PD^2 includes the ability to suggest a flow restrictor size to achieve a desired pad pressure. Be sure to verify the suggested size is available in the standard restrictor kit list below.

475 Restrictors (x/32") - 8, 9, 10, 11, 12, 13, 14, 15, 16, 18, 20, 22, & 24
675 Restrictors (x/32") - 16, 18, 20, 22, 24, 26, 28, 30, & 32
900 Restrictors (x/32") - 26, 28, 30, 32, 34, 36, & 38

1.3 Magnetic Material Removal

Magnetic material present in the mud is highly detrimental to the performance of the PowerDrive control unit. Magnetic material passing through the torquers causes excessive friction and can lead to toolface stability issues or complete torquer jamming. **To mitigate magnetic material related issues, it is mandatory to run ditch magnets in the circulating system and clean them at least twice daily.**

Ditch magnets should be installed in the flow line, header tanks, and/or possum belly of the shale shakers.

Ditch magnets should be installed and cleaned prior to picking up PowerDrive to ensure the tool is introduced to a clean system. When adding pre-mixed mud from an outside source, efforts should be made to run that mud across the magnets prior to pumping it downhole for the first time.

1.4 Tool Specifications

Specifications		PowerDrive X6					PowerDrive Orbit	
		475 X6	675 X6	825 X6	900 X6	1100 X6	475 Orbit	675 Orbit
Mechanical	Nominal OD, in	4 3/4	6 3/4	8 1/4	9	11	4 3/4	6 3/4
	Overall Length, ft	13.65	13.47	13.84	13.84	15.22	13.5	53
	Hole Sizes, in	6 - 6 3/4	7 7/8, 9 7/8	10 5/8 – 11 5/8	12 ¼ – 18 1/2	20 - 28	6, 6 1/8, 6 ¼, 6 3/4	8 1/2, 8 ¾, 9 7/8"
	Bit Speed, rpm	0 - 220					0 - 350	
	Max WOB, lbf	31,000	180,000	270,000	370,000	225,000	31,000	180,000
	Max Torque on Bit, ft.lbf	9,000	18,500	45,000	45,000	70,000	9,000	18,500
	Max Overpull, lbf	340,.000	1,100,000	1,100,000	1,800,000	2,500,000	340,000	1,100,000
	Pass Through DLS (Sliding)	30	16	12	10	4	30	16
	Bit Connection	3 1/2 Reg	4 1/2 Reg or 6 5/8 Reg	6 5/8 Reg	6 5/8 Reg or 7 5/8 Reg	7 5/8 Reg	3 1/2 Reg	4 1/2 Reg
Hydraulics	Flow Range, gal/min [1]	120 - 310	210 - 970	280 - 2,000	280 - 2,000	280 - 2,000	170-310	210-970
	Max Sand Content, %	1						
	Max Low Gravity Solids, %	8						
	Max LCM Material, ppb [2]	35	50	50	50	50	35	50
	Acidity, pH	9.5 - 12						
	Oxygen, ppm	1						
Pressure & Temperature	Max Temp, F	302						
	Max Pressure, psi	20,000						
Measurements	Inclination Offset to Tool Bottom, ft	6.76	7.13	7.60	7.70	9.00	6.93	7.19
	Azimuth Offset to Tool Bottom, ft	8.86	9.33	9.80	9.90	11.20	9.03	9.39
	Gamma Ray Measurements	Average & 4-Bin					Average & 8 or 4-Bin API	
	Gamma Ray Range, cps	0 - 1,000						
	Shock Range, g_n	0 - 625						
	Shock & Vibration Axis	Triaxial						
Automation	Automated Loop	Inclination					Inclination & Azimuth	
	Downlinking Method	Flow & RPM						

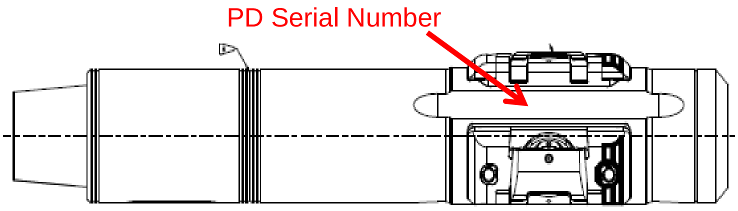
Specification Notes:

1. The Operating Envelop is heavily dependent on mud weight. Heavier mud allows for a lower minimum flow rate. Be sure to consult the tool-specific paperwork to acquire the critical flow rates for each tool.
2. Fibrous LCM such as cotton seed hulls and cedar fiber should be avoided entirely to prevent filter plugging and flow kit jamming.

2 Tool Preparation

2.1 Reviewing Tool Paperwork

The Rotary Steerable Outgoing Systems Test (OST) paperwork is a valuable document for the Directional Driller. This paperwork will be provided by the Extreme Equipment Rental coordinator by the time tools arrive on location. If not, contact the coordinator with the tool serial number so that the correct paperwork can be provided. The tool serial number is stamped in the junk slot area of the bias unit, between two of the PowerDrive pads as shown below.

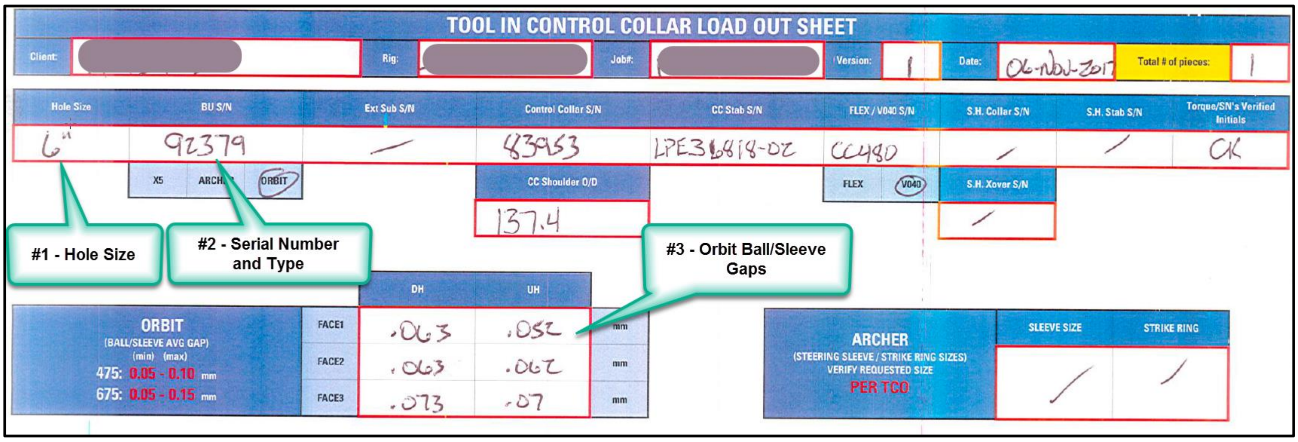


2.1.1 Tool Configuration

The OST paperwork is full of information, not all of which is useful to the DD. Below is a list of the few critical things to verify from each section. A PowerDrive should NEVER be picked up without first verifying the tool is configured to meet the requirements of the job

Tool in Control Collar Load Out Sheet

1. Hole Size – This must match the hole size.
2. Bias Unit Serial Number and Type – Verify the BU type and serial number match what you have.
3. Orbit Ball/Sleeve Gaps – Enter these values into PD[2] as previously described in section 1.2.2.


TOOL IN CONTROL COLLAR LOAD OUT SHEET

Client: [redacted] Rig: [redacted] Job#: [redacted] Version: 1 Date: 06-NOV-2017 Total # of pieces: 1

Hole Size	BU S/N	Ext Sub S/N	Control Collar S/N	CC Stab S/N	FLEX / V040 S/N	S.H. Collar S/N	S.H. Stab S/N	Torque/SN's Verified Initials
6"	92379	—	43953	LPE3 6818-02	CC480	/	/	CK

X5 ARCHER ORBIT; CC Shoulder O/D: 137.4; FLEX V040; S.H. Xover S/N: /

ORBIT (BALL/SLEEVE AVG GAP) (min) (max) 475: 0.05 - 0.10 mm 675: 0.05 - 0.15 mm

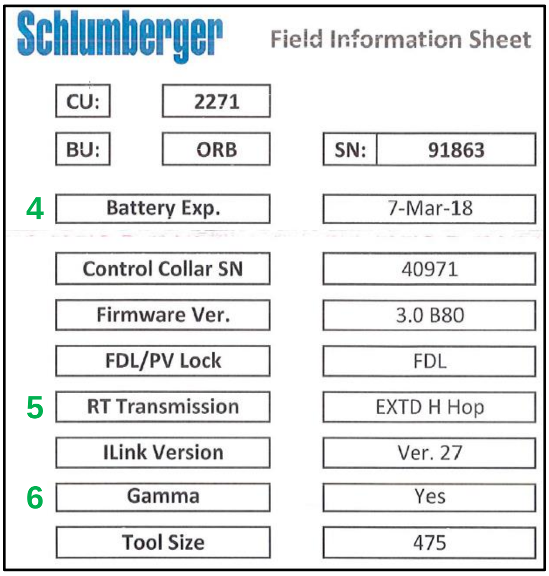
	DH	UH	
FACE1	.063	.052	mm
FACE2	.063	.062	mm
FACE3	.073	.07	mm

ARCHER (STEERING SLEEVE / STRIKE RING SIZES) VERIFY REQUESTED SIZE PER TCO

SLEEVE SIZE	STRIKE RING
/	/

Field Information Sheet

4. Battery Expiration – This is only relevant in the rare event that the client needs recorded mode gamma logs. PowerDrive does not use the battery for normal operation.
5. RealTime Transmission – If running a MWD capable of transmitting PD data, confirm this does not say "Non RealTime" or "NRT".
6. Gamma – Verify the tool contains a gamma sensor if logging is planned.


Schlumberger Field Information Sheet

CU: 2271
BU: ORB SN: 91863

4	Battery Exp.	7-Mar-18
	Control Collar SN	40971
	Firmware Ver.	3.0 B80
	FDL/PV Lock	FDL
5	RT Transmission	EXTD H Hop
	ILink Version	Ver. 27
6	Gamma	Yes
	Tool Size	475

PDCU-xx Tool Configuration Report

Schlumberger

PDCU-CA Tool Configuration Report

Job Information	
Job Name	CCOTLM-17MLR0450-010
Company	[redacted]
Well Name	
Field Name	
County	
State	
Location	
Engineer	
Date	07-NOV-2017(UTC)

	Tool Information	
	Mfg Code/Tool Name	PDX6B/PDCU-CA
	Tool Serial Number	03335
7	Tool Firmware Version	30 b80
	ToolScope Framework Version	ToolScope 20.4.2.5C
	ToolScope PDX6 Version	20.4.5.30
	Tool Description	
	Tool Clock	9303

Tool Configuration Parameters

	Name	Value	Units	Report Name	Group
	CollarSize	4.75		Collar Size	Tool Description
8	DlnkBitPeriod	18	s	Bit period of automated flow downlinks	Initial Steering Settings
	DrillingCycle	180		Duration of drilling cycle	Initial Steering Settings
9	DesiredSteeringMode	0		Initial steering mode: 0=build and turn (Default), 1=PowerV	Initial Steering Settings
10	DesiredToolface	0	deg	Initial toolface angle	Initial Steering Settings
11	DesiredSteeringRatio	0	% max	Initial steering ratio	Initial Steering Settings
12	DesiredToolfaceMode	2		Initial toolface mode, 1=Magnetic (default), 2=Gravity	Initial Steering Settings
	ROPIndex	0	ft/h	ROP index (IH). 0 = 20-100ft/hr, 1= 80-400ft/hr	Initial Steering Settings/Inclination Hold
	DropRate	15	%	Drop rate (IH)	Initial Steering Settings/Inclination Hold
	SlewRate	4	RPM	Neutral slew rate(CU Rotation speed)	Initial Steering Settings
	SlewMode	0		Neutral slew mode(Abs=0,Rel=1)	Initial Steering Settings
	MuleShoeAn	68.54006	deg	Mule Shoe phase angle	Tool Parameters
	TFShiftAn	60	deg	TF phase shift angle(Orbit=60, Xtra=90, X5=120, Archer 675=163, Archer 475=135, CoPiBana=146)	Tool Parameters
	ToolType	3		ToolType (PDX6=0,Archer=1,XTRA=2,Orbit=3,CoPiBana=4)	Tool Parameters
13	UplinkType	1		Uplink Type (0=Std.ShortHop, 1=Ext.ShortHop, 2=Std.Clink, 3=Ext.Clink, 4=Flex.Shorthop, 5=Flex.Clink)	Real Time

7. Tool Firmware Version – The tool firmware version is entered into the downlink timing sheet because different versions have different downlinks available.

8. Downlink Bit Period – The bit period the tool is initially configured to accept. Remember, the tool will always accept 60 second bit period regardless of whether it's in 18 or 36 second mode.

9. Desired Steering Mode – If PowerV, a specific downlink sequence must be sent to "unlock" the tool and allow deviation from vertical. See section 3.8 for more details.

10. Desired Toolface – Initial Toolface setting. Typically, 0 or 180.

11. Desired Steering Ratio – Initial Steering Ratio. Typically, 0% (neutral) or 100% (PowerV Lock).

12. Desired Toolface Mode – Initial Toolface mode. Typically, Gravity.

13. Uplink Type – Use the following Compatibility Matrix to determine what MWD receiver the PowerDrive is compatible with.

MWD Receiver	Uplink Type						Notes
	Standard ShortHop	Extended ShortHop	Flex ShortHop	Clink	Extended Clink	Flex CLink	
ShortHop	Yes	Yes	No	No	No	No	
X-Hop	Yes	Yes	No	No	No	No	Confirm MWD is configured to receive & send Standard, Extended, or Flex data or communication issues will occur.
H-Hop	Yes	Yes	Yes	No	No	No	
C-Link	No	No	No	Yes	Yes	Yes	
CLPS	No	No	No	Yes	Yes	No	

2.1.2 Flow Loop Results

Purpose

The Flow Loop Analysis provides the critical flow rates for each specific tool and allows the DD to adjust these rates depending on mud weight as the run progresses.

Flow Loop Analysis Verification

Tool/Processing Information

MfgCode/ToolName:	PDX6B/PDCU-CA	Processed Date:	Nov/09/2017
Tool Version:	30	Processed Time:	03:24:01 PM
ToolScope Version:	20.4.2.5c	Processor Name:	Meaton
CU Serial Number:	03435	Location Name:	CCO
Flow Kit:	PD475_LF3	SU/Tool Type:	Orbit
Tool Dump File:	D:\TOOLDATA\PD-V30_80\PDX6_03435\Temp\2017_11_09_CU3435_FL--2017-11-09-13-21-47\ControlUnitTests\PDCU-CA_3435_ControlUnitTest_2		

Test Summary

In Water:

Maximum drilling flow rate (GPM):	205
Minimum drilling flow rate (GPM):	166
Minimum tool turn on flow rate (GPM):	99

In Drilling Mud:

1	Mud weight (ppg):	12
2	Maximum drilling flow rate (GPM):	205
3	Density corrected minimum drilling flow rate (GPM):	147
4	Density corrected minimum tool turn on flow rate (GPM):	88

1. Mud Weight – Minimum flow and tool turn on rates are dictated by the flow loop results as well as the mud weight. The higher the mud weight, the more torque that will be exhibited on the flow kit, and the lower flow the tool can handle. If this is not within 0.5 ppg of the planned or current mud weight, the operating envelop on the following page should be used to adjust these critical flow rates.

2. Maximum Drilling Flow Rate – Damage or toolface instability can occur if pumping above this rate.

3. Density Corrected Minimum Drilling Flow Rate – Never pump below this flow rate if drilling. Try to stay at or above this flow rate as much as possible when circulating off bottom to avoid torquer jamming.

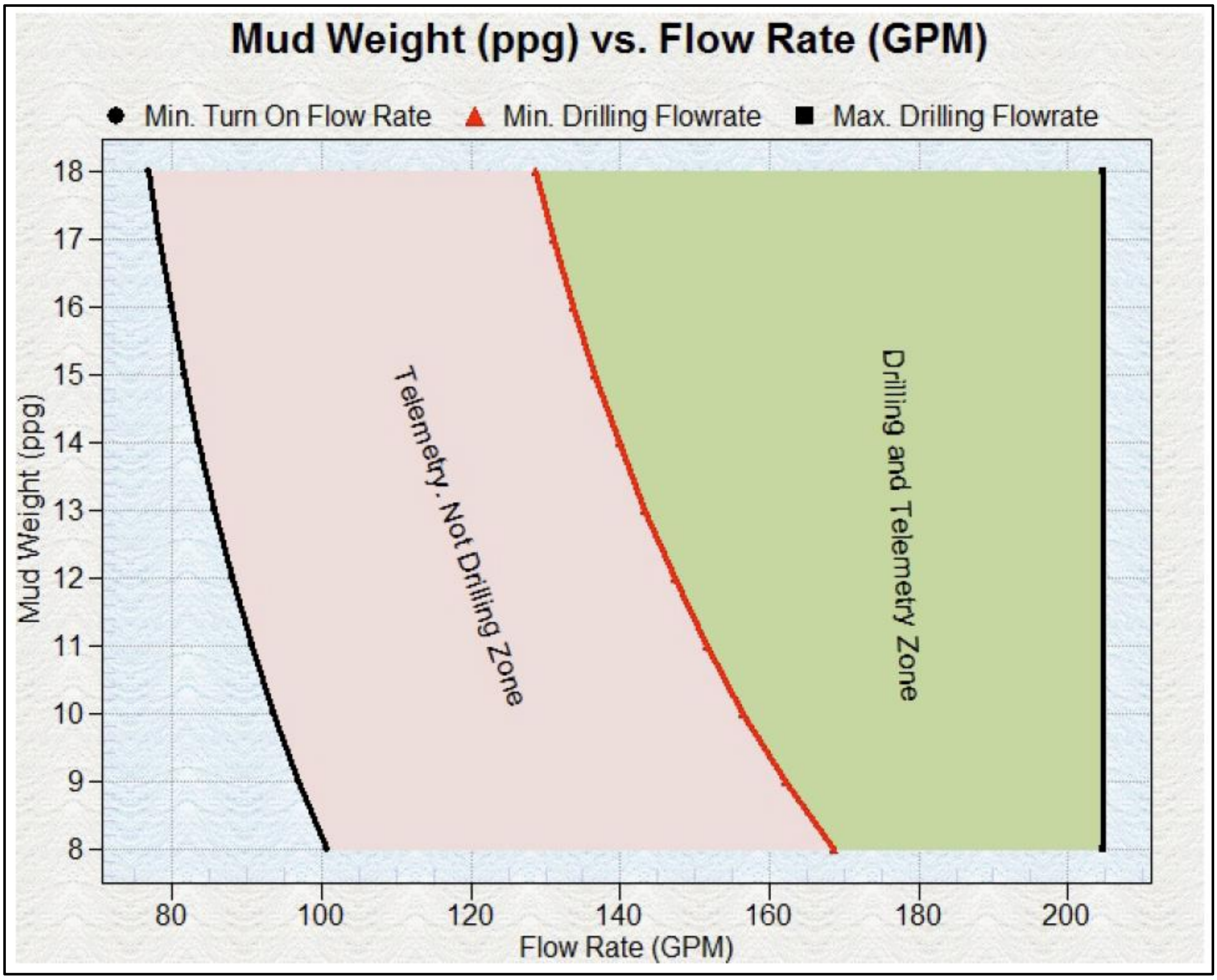
4. Density Corrected Minimum Tool Turn on Flow Rate – This is the flow rate at which the control unit will turn on and record data. While the tool will be on, it cannot steer nor is it cleaning as optimally as it is when flow is kept above the Minimum Drill Flow [4] and therefore the risk of torquer jamming is higher. Never go below this value when downlinking or the tool will turn off and the downlink will be dropped.

2.1.3 Operating Envelope

The Flow Loop Analysis provides the critical flow rates for each specific tool and enables the DD to adjust these rates depending on mud weight as the run progresses. The operating envelop contained in the OST package is specific to that particular tool and is based on the torque measurements taken while flowing that tool in the shop. The DD must be careful to use only the Operating Envelop that matches the exact tool being run since all tools have slightly different ranges.

PowerDrive's steering performance is based upon a balance of frictions. Internal frictions exist within the tool's many bearings and assemblies which the tool must be able to overcome in order hold a steady toolface. This is determined by the Torque output from the flow kit. As mud weight increases, the flow kit generates more torque. Therefore, the tools minimum flow rates will decrease with increasing mud weight.

Before picking up tools, the DD must refer to the specific tool's Operating Envelop and adjust the minimum flows accordingly. This is especially important if a tool was transferred from a different job with different mud weight. If the mud weight is less than what the tool was originally planned for, its minimum flows will be higher. If the flow rates are not adjusted for mud weight, there is a high probability of tool failure due to insufficient torque.



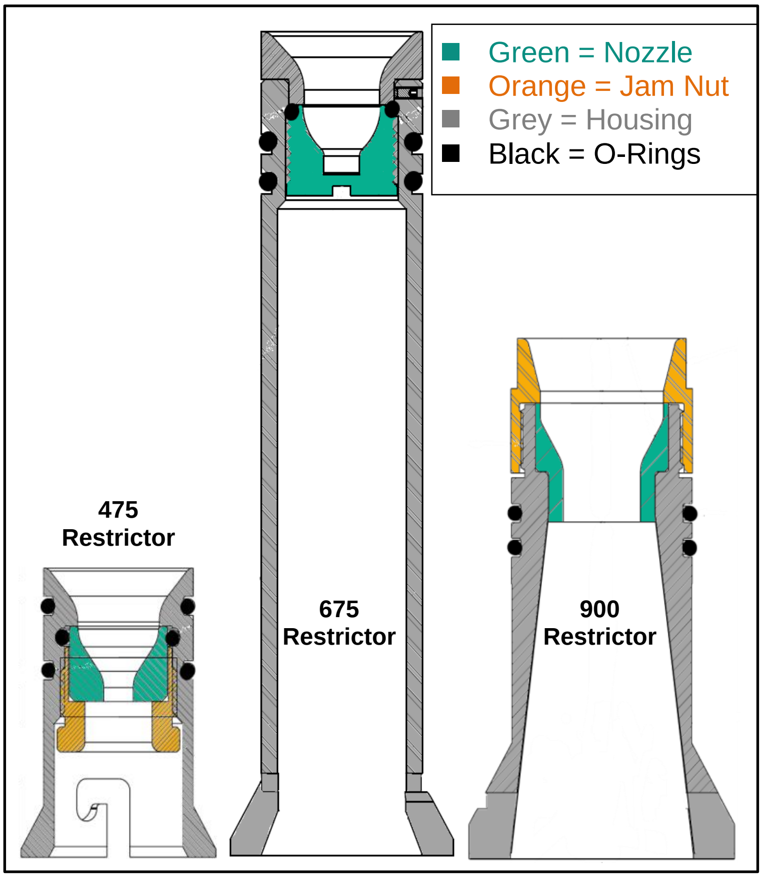
1. <u>Telemetry, Not Drilling Zone</u>: This region can only be used for downlinking (Telemetry) off-bottom. The tool cannot generate enough torque to hold a steady toolface in this range and therefore drilling cannot be done at flow rates below the "Min Drilling Flowrate".

2. <u>Drilling and Telemetry Zone</u>: This region can be used for both downlinking (Telemetry) and Drilling.

2.2 Flow Restrictor Installation

Assembly of the Flow Restrictor is dependent on the size of the body. The 475 uses a threaded lock-nut to hold the nozzle. This set is then inserted through the base of the housing and tightened. The 675 uses a threaded nozzle that is inserted through the base of the housing. The 900 requires the nozzle to be fitted to the top of the body and a lock-nut is then torqued down to secure it. **All connections on the restrictor assemblies should be hand-tight.** Over-tightening can lead to cracks and washout of the restrictor, housing, or Bias Unit.

The Flow Restrictor sits in the base of the bias/steering unit and is held in place by a set of O-rings and secured by the Bit Pin. It should be inserted just prior to making up the bit and removed immediately on breaking off the bit post run to prevent the potential of loss into the open hole.



Flow Restrictor Assembly / Installation Steps:

1. Ensure that the nozzle O-ring has been fitted inside the restrictor body. Not applicable for 900.
2. All nozzles must be fitted in the correct orientation as shown in the assembly schematics above.
3. The nozzle retainers should only be hand-tight. Overtightening will lead to cracking and washout.
4. Ensure that the two O-rings on the OD of the body are in place and undamaged.
5. Insert the restrictor assembly into the “Bit Box” of the PowerDrive Bias Unit. If necessary, the slide hammer can be used to gently tap the restrictor into place. Do not use excessive force with the slide hammer or it may be damaged, preventing it’s use for housing removal at the end of the run.
6. Install and torque the bit.

2.3 BHA Makeup

Torqueing the Bit:

- Tongs should be placed ABOVE the PD pads/kickers when torqueing the bit.
- Never place tongs on the pads or kickers of the bias unit.

Torqueing the Collar:

- Do not place tongs, slips, or collar clamps on any recesses in the PowerDrive control collar including anchor bolt holes.
- In general, tongs should be placed at least 12” from a box, and 6” from a pin connection.

2.4 Surface Testing – Not Advised

It is not recommended to surface test PowerDrive under normal circumstances. The surface test often gives inconclusive results due to magnetic interference from the rig or improper testing procedure. Emag communications can also be intermittent or completely lacking due to interference. The surface test can also cause drilling fluid to overrun the stack and create an environmental issue for some clients. The only time a surface test might be performed is in the event of re-running a tool. This will be covered in Section 3.8.

3 Job Execution

3.1 Tripping In / Filling Pipe

There are no PowerDrive-Specific requirements on how frequently to fill pipe while tripping in.

When filling pipe, it is advised to break circulation and pump at the tool's Minimum Drill Flow for 5-10 minutes. This will help prevent the torquers from jamming with solids or metallic debris before reaching bottom. This is especially critical with mud weights above 12 ppg or when used mud has recently been added to the active system from an unknown source.

Be aware that when PowerDrive is run below a motor, any circulation will result in rotation of the PowerDrive and any other BHA components located below the motor. Use caution and monitor shock and vibration in this scenario, especially while inside casing.

3.2 Reaming / Back-Reaming

During reaming operations, the drill string has greater freedom of motion as it is not constrained by WOB. With this greater freedom of motion comes a greater potential for Shock damage. If running with RealTime PowerDrive Communication, pay close attention to the PD's shock & vibration measurements. MWD shock sensors are mounted up the string and may see reduced shock amplitudes due to their distance from the bit. Reaming at low rpm reduces the energy in the system, decreasing the amplitude and the number of shocks to the tool. **It is recommended to rotate as slow as is practicable to achieve the necessary hole cleaning effects of reaming.**

Reaming in the hole:

In certain formations, it is often necessary to ream small sections while running in the hole. For longer sections of reaming such as a curve that was drilled with a slick BHA, suggest a separate, stabilized reaming run prior to picking up PowerDrive.

<u>If a short period of reaming is necessary while running in the hole</u>:

- **Reduce flow to the PowerDrive's Minimum Drill Flow.** This will reduce pad pressure significantly but still allow for adequate cleaning of the torquers to prevent jamming.
- Be sure to ream at a high penetration rate to avoid forming a ledge and inadvertently sidetracking.
- Set the PowerDrive (TF/%) as if you were drilling this section to prevent an accidental side track.
    - If reaming a curve with DLS greater than 8 deg/100 ft, set the tool in 0/100%.
    - If reaming a lateral, set the tool in 0/25%.
    - For all other scenarios, select the setting that would achieve the DLS of the section being reamed.

Back-reaming:

Ordinarily, back-reaming should not be planned into the drilling program. On occasion, offset well experience may show that plastic formations flow or swell and constrict the wellbore after a given period of time. In these cases, regular wiper trips and back-reaming may be unavoidable. In many other cases, back-reaming is not effective and can actually consume rig time and damage the wellbore and/or our BHA components.

<u>If back-reaming becomes unavoidable</u>:

- Drill the stand down, pick up off bottom, and reduce the rpm to approximately 40 to 60 rpm.
- **Reduce flow to the PowerDrive's Minimum Drill Flow**. This will reduce pad pressure significantly but still allow for adequate cleaning of the torquers to prevent jamming.
- Monitor real-time shock and vibration levels from the BHA and monitor the annular pressure readings if available.
- Slowly start backreaming while continuously monitoring real-time data.

3.3 Casing Drillout

When drilling out the shoe, keep in mind that Cement Plugs, Float Collar, Cement and Shoe Track are very different materials compared to the formation intended to drill. The bit is not designed to drill this material, especially when drilling in a soft rock environment where bits with low blade count and big cutters (aggressive design) are used.

The real-time shock and vibration levels should be actively monitored, and steps taken to mitigate shock and vibration levels. The stick slip measurements use the tool's magnetometers to detect collar rotation, so the measurement will be unreliable inside the casing. Stick slip can still be detected on surface from erratic and cyclic torque and RPM readings

The following guidelines for drilling out of the casing shoe and rathole should be followed:

1. Inclination hold mode or HIA mode must not be used while drilling out the casing shoe.
2. During the drilling of both the shoe track and the shoe, the flow rate should be reduced to approximately 75% of planned drilling flow (yet above the minimum drilling flow rate of the Control Unit). This reduces the pressure drop across the Bias Unit seals and limits the degree of contact between the pads and the casing.
3. Rotary speed should be limited to approximately 60 rpm while inside the casing string to minimize shock and vibration.
4. Start drilling Float equipment with medium RPM and low weight. Watch shock and vibrations and adjust parameters accordingly. Slow down whenever a material change is expected. Watch shakers for pieces coming up. Always use float equipment with a locking feature to assist in drill out.
5. Increase the rotary speed only when the uppermost stabilizer is out of the shoe and into new formation.
6. When drilling through the casing shoe and the larger diameter rathole, the BHA is unconstrained and is susceptible to extremely high shocks. This can lead to catastrophic hardware failures. Monitor shock and vibrations closely as soon as you start drilling. Manage this problem by monitoring shocks and keeping the RPM as low as practicable until all the stabilizers have entered the newly-drilled gauged hole.

3.4 Downlinking

3.4.1 Downlinking Basics

Downlinking is the method by which a directional driller communicates with the PowerDrive tool to change steering settings. PowerDrive X6 and Orbit can accept both Flow and Rotary downlinks. Flow downlinks are sent by varying the flow rate between high and low levels, typically 20% variance. Rotary downlinks are sent by varying the surface RPM between high and low levels. The variance for Rotary downlinks must be at least 40 RPM.

Warning: When sending Rotary downlinks to X6, the downlink timing sheet will need to be "tricked" by selecting Orbit. This is because X6 outside of the U.S. cannot accept rotary downlinks.

There are 3 different bit periods available when sending downlinks. 18 second, 36 second, and 60 second. Just as a pulse MWD system might require slower and larger pulses as depth and mud weight increase, PowerDrive may require larger bit periods and greater variations in flow as depth and mud weight increase. The typical downlinking times are as follows. They may be longer if downlinking immediately after a connection:

Bit Period		Downlink Time
18 Second	→	4:57 minutes
36 Second	→	9:54 minutes
60 Second	→	16:30 minutes

At any time, PowerDrive Orbit and X6 can detect the following downlinks:

- Flow Downlink at 18 or 36 seconds. **Verify the initial setting using the Tool Paperwork**
- Flow Downlink at 60 seconds
- Rotary (RPM) Downlink at 36 seconds
- Rotary (RPM) Downlink at 60 seconds

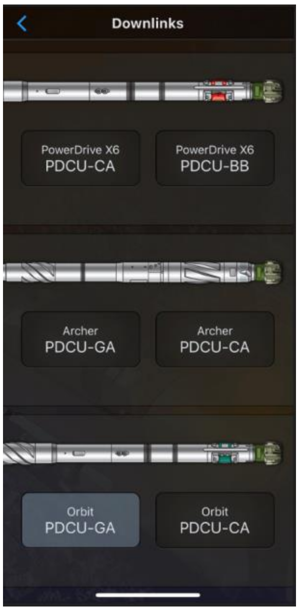
If sending several downlinks in a row, such as when kicking-off from vertical or when nudging up several degrees, the following waiting times between downlinks must be followed:

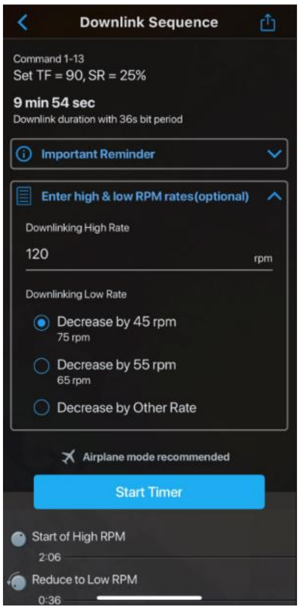
Bit Period		Waiting Time
18 Second	→	1.5 minutes
36 Second	→	3 minutes
60 Second	→	5 minutes

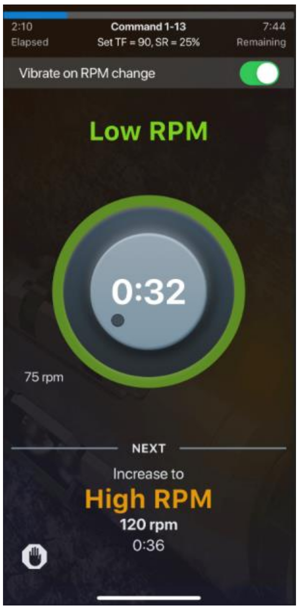
3.4.2 Sending the Downlink

The PowerDrive App is currently the only supported method to downlink to PowerDrive. It is recommended to have your phone in airplane mode during a downlink to minimize interruptions. To send a downlink, the following steps must be followed:

1. Open the App and select the “Downlinks” button
2. Select the Tool Type and manufacture code as verified on the OST
3. Select the Downhole Software Version
4. Select the CURRENT tool mode (Manual Toolface, IH, HIA, PowerV)
5. Select the downlink type (Flow or Collar RPM)
6. Select the Bit Period
7. Select Yes or No whether the tool has been powered up for 3+ minutes
8. Select the desired downlink. Note the manual settings can be found by clicking the “Choose TF and SR Command” button.
9. Enter your high flow/RPM rate and then select one of the options for the low rate. Note these high/low rates and ensure they are used for the entire downlink.
10. Click “Start Timer”
11. Follow the on-screen timing commands for high/low rates through out the duration of the downlink. Note, if the downlink is stopped for any reason you will need to wait through the quiet period which the timer in the App counts down.
12. Once the sequence has been completed, type the current depth. If Real-Time Communication is available from the PowerDrive, confirm downlink acceptance using PDSTEER as shown on the screen. Click “Done”
13. The next downlink cannot start until the required wait time has been completed.







3.5 Kicking Off from Vertical

PowerDrive tools can be used to kick off from any inclination with extensive experience in vertical kickoffs. The following points must be considered when kicking off from vertical:

1. Make any azimuth corrections early, as large changes can be made easily at low inclination
2. Do not work pipe close to bottom on connections to avoid wiping out initial build-up doglegs. Minimize hole enlargement

It is recommended that you initiate the kick-off in MTF mode at 100% steering ratio, and then change to GTF mode when the hole inclination is at least 2°. It is common to switch over to GTF mode when the inclination is 6°-8°.

3.6 Inclination Hold (IH) & Hold Inclination and Azimuth (HIA)

3.6.1 Inclination Hold (IH)

Inclination hold is a PowerDrive steering mode that allows the tool to steer at a target inclination. This feature is designed to drill in tangent and horizontal sections and hold an inclination while reducing the overall downlinks that the Directional Driller will need to put in. While in this steering mode azimuth is adjusted through corrections by incrementally increasing the steering ratio in either the left or right orientation. Inclination Hold cannot be used under 3° inclination. Between 3° - 10° inclination it can be used cautiously. Above 10° inclination is the normal operating range.

Before engaging Inclination Hold, you must obtain a good static survey to give you an accurate reference inclination.

1. Go off bottom
2. Stop rotation
3. Cycle the pumps to reset the tool (bring the pumps down and back up again)
4. Wait at least 3 minutes for a static survey to be taken
5. Downlink to engage Inclination Hold using one of the following three sequences

Command	Effect
2-17	Engage Inclination Hold, with no turn correction
2-18	Engage Inclination Hold, with 12.5% turn correction to the right
2-20	Engage Inclination Hold, with 12.5% turn correction to the left

When in Inclination Hold (IH) mode, the inclination can be adjusted in steps (nudges) of 0.5°:

- Downlink command 2-22 will nudge the inclination target up by 0.5°
- Downlink command 2-23 will nudge the inclination target down by 0.5°

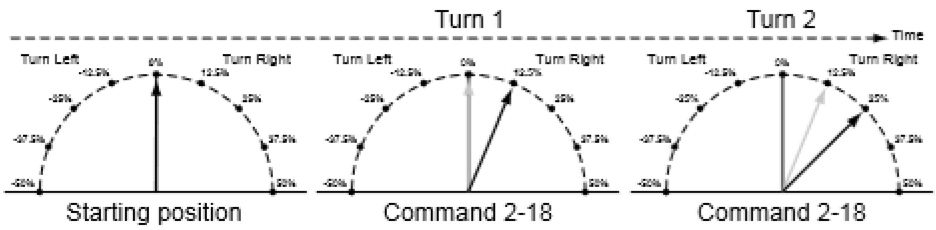
When you use IH mode the tool will slowly approach the target inclination. When a single nudge is applied, it adds 0.1° per drill cycle, so it will take 15 minutes before the full 0.5° nudge will take effect. If two nudges are sent at the same time, it will add 0.5° in the first drill cycle and then add 0.1° during the next five drill cycles. If three nudges are sent at the same time, it will add 1.0° in the first drill cycle, and add 0.1° during the next five drill cycles.

When in Inclination Hold (IH) mode, the azimuth turn correction can be adjusted in steps:

- Downlink command 2-18 will increment the azimuth turn correction (more to the right).
- Downlink command 2-20 will decrement the azimuth turn correction (more to the left).

Put in azimuth turn correction while in inclination hold

To turn the tool to the right while in inclination hold, send command 2-18. The tool will turn in +12.5% steering ratio increases for every command sent to a maximum of 50%. To turn PowerDrive to the left, send command 2-20 and just like the right-hand turn, the tool will increase the steering ratio 12.5% each time. PowerDrive will continue to turn until the turn correction is taken out. The following figure shows two 2-18 commands being sent to the tool increasing the steering ratio 25% to the right:

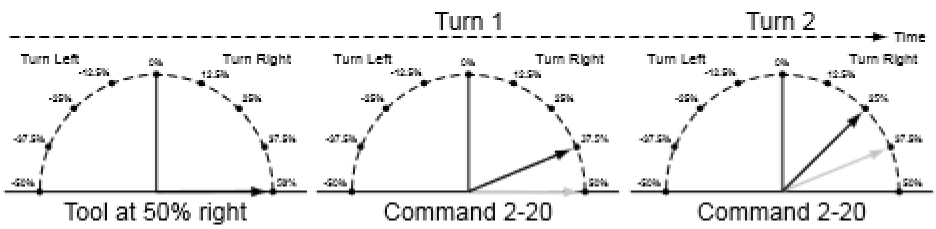


Note:
In Inclination Hold mode:

- You cannot make small changes to the tool's Steering Ratio or TF azimuth angle.
- You can only steer the tool left or right by increasing or decreasing the SR in steps of 12.5%.
- The maximum SR is 50% of the tool's maximum build rate.

Change turn correction left to right while in inclination hold
When in inclination hold the tool can be steered left to right using a series of commands. Command 2–17 is used to bring the tool back to the 0% turning position. The turn correction right command 2-18 is then used to steer the tool right. **You do not have to send multiple 2-18 commands to get the tool back to 0%. Sending command 2-17 will always bring the tool back to 0%.**

Reduce turn correction while in inclination hold
When in inclination hold the turn correction can be reduced. For example, if you are drilling with 50% turn correction to the right, you can reduce the turn correction by sending a turn correction left downlink sequence. The turn correction will be reduced by 12.5% for every turn correction left downlink sequence you send. The following figure shows the tool starting at 50% turn correction to the right, then two 2-20 commands are sent to the tool to reduce the turn correction to 25% right:



Disengage Inclination Hold
To disengage Inclination Hold mode you must send any absolute steering setting, commands 1-0 to 2-12 from the Manual Downlink command list. The increase/decrease toolface and increase/decrease steering ratio do not disengage inclination hold.

After inclination hold is disengaged, the tool will remain in GTF mode.

3.6.2 Hold Inclination and Azimuth (HIA)

Hold inclination and azimuth (HIA) provides simultaneous closed loop control of inclination and azimuth which can be used to drill in laterals, tangents and low DLS profiles. **HIA will not engage at inclinations of less than 10° or more than 170°.** This steering setting can be downlinked using command 2-30. When engaged, HIA will 'hold' the inclination and azimuth captured at the last good PowerDrive static survey.

While engaged in HIA, target inclination and target azimuth can be nudged independently. Inclination is weighted more than azimuth, which means the tool prioritizes inclination over azimuth if it is aiming for both.

Before you engage HIA you must do a static survey to obtain accurate references for inclination and azimuth. It is recommended you do the steps that follow:

1. Pull the tool off the bottom.

2. Stop the tool rotation
3. Cycle the pumps to take a survey.
4. If available, check for a good static survey by monitoring INCL_b and AZIM_b. If they deviate significantly from their acceptable values, then either continue in manual mode or do the survey again.
5. Send downlink command 2-30 to engage HIA. Note: Tool will switch to GTF after it engages HIA
6. If available, monitor IH_TRGT_b and AZI_TRGT_b to make sure they are acceptable. If they are not correct, then disengage HIA and then either continue in manual mode or do the survey again and engage HIA again.

Nudge the Inclination

The target inclination nudge size is fixed at 0.5°. Use the downlink commands that follow to change the target inclination:

- **2-22:** Increase target inclination by 0.5°
- **2-23:** Decrease target inclination by 0.5°

The inclination nudges are applied over five drilling cycles in steps of 0.1°. If several nudges are sent then all but the last nudge will be applied immediately, the last nudge will be applied gradually.

Nudge the Azimuth

The target azimuth nudge size depends on the tool's inclination.

Inclination (°)	Azimuth nudge size (°)
10	11.5
20	5.8
30	4.0
40	3.1
50	2.6
60	2.3
70	2.1
80	2.0
90	2.0
95	2.0

Use the downlink commands that follow to change the target azimuth:

- **2-18:** Increase target azimuth
- **2-20:** Decrease target azimuth

The azimuth nudges are applied over five drilling cycles. If several nudges are sent then all but the last nudge will be applied immediately, the last nudge will be applied gradually

Disengage HIA

To disengage HIA, send an absolute downlink command: 1-0 thru 2-12. **Tool will remain in GTF after it disengages HIA.**

3.6.3 Rate of Penetration Ranges

Inclination Hold and Hold Inclination and Azimuth have a downlinkable ROP Index, which can be changed based on the ROP. The ROP index will define the gain of the Inclination control loop. In some cases, at high rate of penetration, PowerDrive may oscillate around the target inclination. This oscillation can cause micro-dogleg, increasing the tourtosity of the well. In this case it is recommended to reduce the gain by downlinking command 2-21 Low Gain. **It is recommended to only downlink into the Low Gain setting if needed and not based on the actual ROP.** If PowerDrive is downlinked into the Low Gain setting and there is no improvement, then it is recommended to go back to the High Gain setting.

3.7 PowerV Lock/Unlock

PowerV mode is a vertical drilling mode using Gravity Tool Face (GTF) with a tool face of 180 degrees and a steering ratio of 100%. The result of this setting is that PowerDrive will continuously seek to drill vertical without further input from the directional driller at surface. The tool can either be configured in PowerV mode at the shop or downlinked to engage PowerV while drilling. When the tool is in PowerV mode it only responds to the downlink commands given in the following table:

Command	Description
2–29	PowerV Unlock/Engage
2–24	Downlink bit period (18 seconds)
2–25	Downlink bit period (36 seconds)

Disengage PowerV

To disengage PowerV mode two consecutive downlink commands are necessary. It is critical that the time constraints are strictly followed. The image at the end of these steps shows the entire process in its entirety.

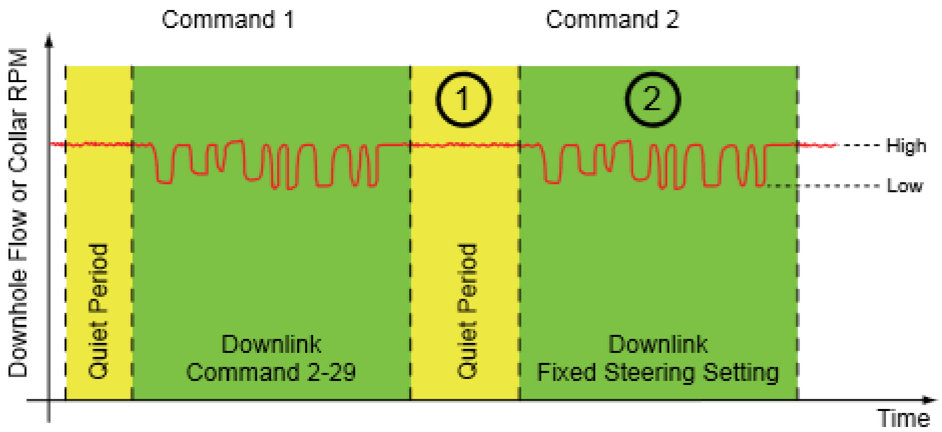
1. After ensuring that the tool has been powered up and the correct quiet time has passed, as shown in the following chart, send command 2-29, PowerV Unlock/Engage to the tool.

Bit Period	Steady flow time (minutes)
18	3
36	3
60	4

2. Stabilize the stand pipe pressure by keeping steady flow for the quiet period given in the following table:

Bit Period	Waiting time (minutes)
18	1.5 to 3
36	3 to 6
60	5 to 10

3. Send a fixed steering setting command to the tool (1-0 to 2-12). Note: It is critical that this downlink is started within the range provided in the table.



When the tool disengages from PowerV mode, it engages MTF mode.

Engage PowerV

To engage PowerV mode two consecutive downlinks are necessary. Both commands are the command 2-29, PowerV Unlock/Engage. The two PowerV Unlock/Engage commands must be sent consecutively.

To engage PowerV mode, do the steps that follow:

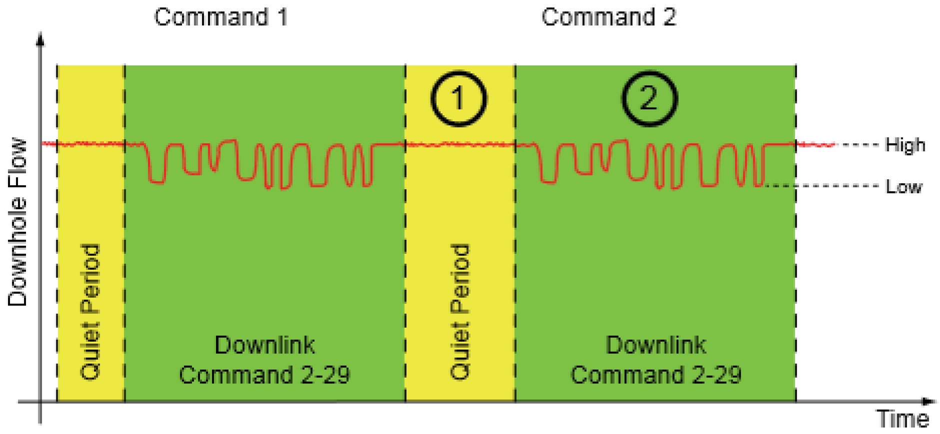
1. After ensuring that the tool has been powered up and the correct quiet time has passed, as shown in the following chart, send command 2-29, PowerV Unlock/Engage to the tool.

Bit Period	Steady flow time (minutes)
18	3
36	3
60	4

2. Stabilize the stand pipe pressure by keeping steady flow for the quiet period given in the following table:

Bit Period	Waiting time (minutes)
18	1.5 to 3
36	3 to 6
60	5 to 10

3. Send command 2-29 again, PowerV Unlock/Engage, to the tool. Note: It is critical that this downlink is started within the range provided in the table.



PowerV mode is now engaged.

3.8 Sidetracking

All PowerDrive tools can be used to sidetrack a well. Typical sidetrack applications are a cement plug, either in a vertical or deviated well or an open hole sidetrack, however in the case of an open hole side track more care is required. Factors affecting the success of a sidetrack are the strength of the cement plug, the existing hole profile, formation drillability and ensuring that adequate time is taken. Although successful sidetracks have been achieved at all inclinations, both from cement plugs and open hole, there are some situations where it will not be possible to sidetrack, such as soft cement and hard formations.

Sidetrack off a cement plug

All PowerDrive tools can be used to sidetrack a well from a cement plug, either in a vertical or deviated well. Open hole sidetracks can be performed, but more care is needed. As a guideline, the following procedure should be used if there is no previous experience of successful sidetracking. Use of real-time inclination will give an early indication of the progress of the sidetrack. Note: Cement cannot be pumped though any PowerDrive system. There is a risk of plugging the tool and BHA and causing serious damage to the internal components.

1. After making up the BHA, and before any circulation is attempted, make sure that the drillpipe is clean and clear of any cement debris that may have accumulated when the cement plug was being pumped. Use drillpipe rubber or sponge balls behind the cement when displacing to clean the drillpipe.

2. Allow the cement plug adequate time to harden. The cement plug must be of sufficient quality and quantity. Avoid plugging the bit nozzles by washing down with a minimal flow rate until the cement is tagged. The flow rate for washing down must be above the tool's minimum flow rate.
3. If the cement plug is not firm, the sidetrack should not be attempted on highside and should be replanned with a low side exit if applicable.
4. If the cement is of sufficient quality, increase the flow rate and drilling parameters to 75% of normal drilling levels, and dress off the cement plug to the required kick off depth. The top of the cement plug will often be of poor quality due to mud contamination in the transition but, will harden with depth.
5. Make sure that the drillpipe is spaced out to allow the sidetrack to be initiated without having to make connections. Space should also be left above the sidetrack point to allow the pipe to be worked.
6. Set the tool to a suitable toolface with the maximum steering ratio (100%). Depending on the existing profile of the hole and proximity to offset casing strings, either magnetic or gravity steering can be used for the kickoff. Do not use the inclination hold mode or HIA mode for kicking off.
7. If the cement plug is firm and able to take weight, attempt to drill off using normal drilling RPM but controlled ROP.
    a. Control the ROP to 10% of the drilling rate at the same depth in the main wellbore. Maintain this rate until a clear indication of new formation is seen in the returned cuttings. Do not increase the ROP until new formation is seen in the cuttings.
    b. When new formation is seen in the cuttings, increase the ROP to 30% of the offset ROP until 60% new formation is seen in the returned cuttings.
    c. When 60% of cuttings are seen, increase the ROP to 60% of the offset ROP until 100% new formation is seen with no more than trace cement.

Note: The time taken to sidetrack will depend on the relative strengths of the cement and formation and can vary from ten minutes to 24 hours or more.

8. If the cement plug remains soft, consider either waiting for the cement to harden or proceeding with the sidetrack. More care and patience will be needed in this case. It may be possible to set another cement plug if the first sidetrack fails.
9. After the sidetrack has been initiated, closely monitor the inclination to avoid excessive doglegs, and monitor the cuttings for indications that the new hole may have started to track back into the cement plug.

Open hole sidetracking

All PowerDrive systems can be used for open hole sidetracks to the low side. Use of real-time inclination will give an early indication of the progress of the sidetrack. As a guideline, the following procedure should be used if there is no previous experience of successful open hole sidetracking.

- The success rate for open hole sidetracks is dependent on the formation drillability, it may be impossible to sidetrack if the formation is too hard. Hole inclination also plays an important role. Open hole sidetracks should only be considered above 70° inclination. Subsequent BHAs and casing strings or liners will need to pass the sidetrack, making the transition from the original hole under the influence of gravity.
- Try to choose a sidetrack point with an abrupt change in profile or change in formation. A good example is the transition between a rotated interval and an oriented interval in a section of hole previously drilled with a motor. Consult the parameter sheets and plot continuous inclination against depth to aid choosing an appropriate sidetrack point.
- Choose a sidetrack point as shallow as possible to allow a second sidetrack point to be chosen at a deeper point, and still achieve the directional objectives.
- Depending on the formation drillability, an open hole sidetrack can take anywhere from one hour to over 24 hours to initiate. Patience is vital to make sure that the first ledge that is created is maintained and enlarged as the sidetrack progresses.
- Make sure that the drillpipe is spaced out to allow the sidetrack to be initiated without having to make connections. Space should also be left above the sidetrack point to allow the pipe to be worked and the sidetrack transition to be reamed.
- The open hole sidetrack is initiated by creating a ledge on the lowside of the hole. This ledge is then elongated until the sidetrack deviates completely from the parent wellbore.
- Set the tool to the desired sidetrack toolface (usually lowside) using 100% steering and commence reaming with high RPM and low ROP. Mark the drillpipe at the sidetrack depth, and

ream down to this mark over a 15 ft to 30 ft (5 m to 10 m) interval. The reaming ROP should be 5% to 10% of the drilled ROP in the parent wellbore, and RPM should be drilling RPM or 120 rpm to 150 rpm.

- It is important not to ream beyond the sidetrack depth or the ledge will be destroyed. The time taken to initiate this ledge will depend on the formation drillability and hole inclination. As a rule of thumb, ream downwards to the sidetrack point up to 10 times at 5% to 10% of the drilled ROP. Indications of the ledge being created will be a small increase in WOB or change in continuous inclination.
- Commence controlled drilling at 10% to 15% of the drilled ROP monitoring WOB and continuous inclination to avoid creating excessive doglegs.
- As the sidetrack progresses the Bias Unit steering pads will not be in contact the high side of the hole. The side cutting action of the bit, high RPM and the side force created by gravity are the primary sidetracking mechanisms.
- After the sidetrack has been initiated, closely monitor the inclination from the tool to avoid excessive doglegs.
- With an open hole sidetrack, it is particularly important to carefully ream the sidetrack transition to make sure that it is clear from debris and as smooth as possible.
- After the sidetrack has been initiated, and preferably before making a connection, reduce the RPM to between 40 rpm and 60 rpm, and slowly backream through the transition. Shock and Vibration levels should be monitored as well as indications of overpull or packing off. Reduce the pump rate and RPM then run back through the transition at approximately twice the normal drilling rate. Repeat this procedure twice more. Stop if there is any sign of hanging up.
- If the BHA hangs up, increase the flow rate and set the PowerDrive toolface to lowside (or the sidetrack direction). Run back through the sidetrack transition. Use of real-time inclination will confirm entry into the sidetrack wellbore.
- On subsequent trips though the sidetrack transition, care should be taken to avoid damage to the transition and entering the original hole. Use of real-time inclination from the PowerDrive tool is beneficial in confirming entry into the sidetrack.

Casing exits and whipstocks

All PowerDrive tools can be used to sidetrack off a whipstock. However, it is not recommended to drill directly off the whipstock unless there is a suitable length of rat hole. This will help to ensure that the PowerDrive is not damaged by rotation over the whipstock or window.

Experience has shown that significant tool damage occurs if the PowerDrive tools are rotated in contact with the whipstock body. The following procedure is recommended:

- Ensure a sufficient length of rat hole is drilled with the mill assembly, 9 ft to 15 ft (3 m to 5 m) minimum is recommended.
- To avoid the possibility of the milling assembly damaging the anchor slips an extension should be added between the whip face and the anchor slips.
- Window milling and kicking off from a whipstock is a specialized operation and the service provider should be consulted prior to the job. There is always a risk of the milling assembly tracking the casing and failing to kick off in the following circumstances:
  - The milling assembly is too flexible
  - The length of rat hole is too long, and separation from the original hole has already been lost.
  - The length of rat hole is shorter than absolutely necessary to allow the PowerDrive stabilizers to clear the window
  - The mills are unable to cut laterally in hard formations as the window is exited
  - Poor quality cement
  - Milling multiple casing strings.
- Make sure mills are in gauge after window milling (make sure they have been correctly gauged).
- Initially run through the window without rotation or flow. Do not rotate the tool through the window to minimize bit and pad damage when running in/out of hole.
- If resistance is encountered, the PowerDrive toolface can be oriented to the whipstock direction and the tool rotated slowly with a reduced flow rate. Do not rotate more than 25 rpm to avoid damage to the tools.

- Start drilling with reduced WOB and RPM to minimize potential of localized shocks to the PowerDrive Tools (often not seen on the MWD). If high levels of shock and vibration are seen, stop drilling.
- If other stabilizers are included in the BHA, control surface RPM to approximately 60 rpm as the stabilizers pass the window.
- Monitor the levels of magnetic interference as drilling progresses to ensure that the BHA is not tracking down the side of the casing string.
- When drilling ahead out of a whipstock, the MWD/LWD tools maybe exposed to DLS higher than their specifications (especially if rotation is planned with part of the BHA across the whipstock face). It is important that these operations are discussed with the Client at the planning stage.

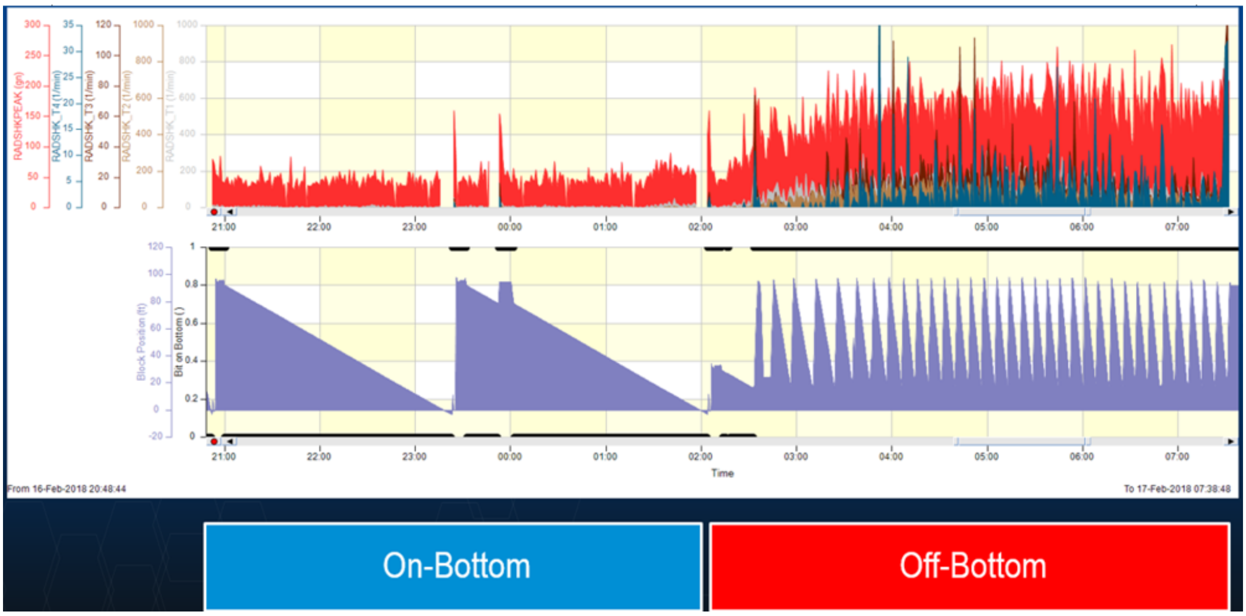
When exiting casing or sidetracking off a whipstock:

- Make sure that the Bias Unit and Control Stabilizer have passed the window before rotating.
- If required, wash through the window without rotation and using low flow to prevent Bias Unit pad damage. Make sure that no tight spots are encountered.

When using a motor with PowerDrive, the lower part of the BHA below the motor will always be rotating when the pumps are on. Thus, the practice of washing past the whipstock face will still involve some rotation of the PowerDrive tool.

3.9 Cleanup Cycles

Upon reaching TD it is normal for a client to perform a cleanup cycle. While performing a cleanup cycle it is critical that drilling parameters are closely monitored for shock and vibration. It is not uncommon to drill a well successfully to TD and then damage a PowerDrive during the shock and vibration induced during a cleanup cycle. It is strongly recommended to perform as much of the cleanup cycle on bottom as possible. The following graphic shows the difference in shock and vibration on-bottom vs off-bottom. The left side of the graphic shows the last 2 stands drilled with minimal shocks and on the right side of the graphic the client is performing an off-bottom clean-up cycle and devastating shocks are recorded.



It is vital to discuss the cleanup cycle with the client prior to starting the operation. The following procedure is a best practice to minimize damage.

For the last stand before TD:

1. Control the **ROP to 10-15'/hour**, keeping the same drilling flow rate and **100 surface RPM**
2. Lower the ROP to <10'/hour if more circulation is needed
3. Watch the real time chock closely, change drilling parameters if needed
4. One bottom up circulation after reaching TD, then POOH

3.10 Re-Run Evaluation

When evaluating if a PowerDrive can be rerun, the PowerDrive Rerun Checklist should be used. This spreadsheet will determine if the tool can be “Re-run”, “Re-run – Proceed with Caution”, or “Tool should not be re-run”. The following questions are asked as a part of the re-run criteria. If the re-run checklist is not available, use these questions as a discussion on whether the PowerDrive should be rerun.

Post Run(s) Information

- Was the PowerDrive Orbit the reason for pulling out of the hole? If so then it should not be rerun.
- While monitoring the real-time data was there any indication that the tool was having issues maintaining toolface? Was the tool operating as intended?
- What was the maximum shock level that the tool saw over a 30-minute duration? If catastrophic shocks (Level 3) are maintained, then the tool should not be re-run.
- What was the maximum temperature on the run? Anything above 150° C is over the tool’s rated limits and should not be run again.
- How many pumping hours are currently on the tool? There is no limit to how long a PowerDrive will theoretically operate for, however as the pumping hours increase the tool can start to see a decrease in performance due to wash, friction increases, pad wear ect. The environment in which this tool is operating in will need to be considered to determine if an hour limit will be placed on PowerDrive.
- What is the average bit RPM? If the average is over 350 RPM, then caution should be used before rerunning.
- Is there LCM present in the mud system? Was it introduced during the run or at the end? If the LCM is compatible with PowerDrive as shown in the LCM charts, then there should be no issue. However if the LCM contains cotton seed hulls or cedar fiber then the tools should not be re-run as there could be issues with plugging the filter screen or jamming.
- Are the ditch magnets present and have they been regularly monitored and cleaned? If not, then the tool should not be re-run.
- Has there been evidence of elastomer in shakers or in tool/bit (possible motor chunking)? If yes, then the PowerDrive should not be re-run as there is a high risk that the rubber has gotten into the tool and will cause the PowerDrive to jam.

Post Run(s) Surface Observations

- Are the pads excessively worn?
  - Grade 1: No buttons or tiles exposed.
  - Grade 2: Buttons or tiles exposed but no groove around them. No worn edge on the sides.
  - Grade 3: Light wear on edges. Buttons or tiles with groove around them.
  - Grade 4: Heavy wear on edges. Buttons or tiles removed. External face is damaged.
- Are the Bias Unit sleeves cracked? If so, the tool should not be re-run.
- Can the pads open freely? If not, the tool should not be re-run.
- Is a hinge pin broken? i.e. Can the pad move, other than pivoting on the hinge pin? If so, then the tool should not be re-run.
- Does the flow restrictor body/carrier have signs of internal erosion? At a minimum the flow restrictor body will need to be replaced. However it is important to note that if this component is washing, then most likely there is additional wash internal to the tool, proceed with caution.
- Are the anchor bolts present without wash or cracks?
- Is the stabilizer suitable to run again (Recommended 1/8” under gauge)?

Between Runs

- Was the tool flushed with water (WBM) or base oil (OBM) prior to being racked? If not, proceed with caution.
- Was the tool racked back for over 24 hours?
- Was the tool stored at a temperature below 0° C?

Next Run

- What is the expected run length? This will need to be considered along with previous pumping hours.
- Do the flow rates and mud weight in the next run comply with the current tool set-up?

4 Troubleshooting

4.1 Low Dogleg Workflow

Low doglegs can occur due to Insufficient pressure drop across the pads, insufficient pad force, high RPM, stick-slip, formation effects (Soft or unconsolidated formations or strong formation push), jamming, bit selection, BHA design or tool failure.

When troubleshooting low dogleg, the following steps should be taken:

- Check Realtime Diagnostics (if available). PROPEFF should match PRDS_b. If not, jamming or stick-slip could be reducing the Control Unit's ability to hold a steady toolface. Don't rely on LTRPM (lower torquer RPM) alone as this may not flag.
- Reduce RPM. Attempt to get as close to 100 as possible but be careful not to allow stick-slip to initiate, which will further reduce DLS response.
- Increase Pad Pressure. Exceeding the recommended range for X6 or Orbit increases the likelihood of damage to the tool and should not be done without management approval.
- Reduce ROP. This is particularly helpful in fast-drilling formations. Reduce ROP to ~50% of maximum attainable ROP

4.2 Anti-Jamming Procedure

The nature and size of the debris/ particles causing jamming events are different and require differing steps to address the problems. Primary failure causes are:

1. Jamming of the impeller relative to the collar. Typically caused by large scale debris such as stator rubber from motors, plastic tie wraps and other foreign items.
2. Jamming of the magnet housing relative to the torquer body. Typically these events are caused by fine grade material dropping out of the mud system as the fluid passes across the torquer assembly. Failures have been found due to LCM, barite, clay / shale and metal filings.
3. Blockage of the bias unit filter assembly. Typically due to LCM material. Failures of this nature are rare as the filter is designed to be self-cleaning, however problems may occur depending on the pill mixture being pumped

When it is confirmed that the PowerDrive tool is jammed and the tool has lost its directional function, the following anti-jam attempts can be tried at the rig site. The steps are independent and repeatable by itself and shall not be all performed at one time. An evaluation of the result after each attempt must be done before moving to the next step:

1. Pump the tool at maximum flow (within the operating range of the tool) for 15 minutes.
2. Attempt to turn on the tool by bringing the flow up as fast as possible up to maximum drilling flow.
3. Pump a low vis sweep immediately followed by a high vis sweep. Sweeps can range from 20-30bbl depending on hole conditions.
   - Low Vis Sweep includes the following:
     - Drop Vis 15-20 seconds
     - For OBM – Dilute with Diesel
   - High Vis Sweep includes the following:
     - Increase Vis 10-20 seconds
     - 5-10 Sacks of PURE Non-Metallic Graphite ***Check for metal with a magnet***
     - Mud Weight should stay the same as the MW in the Tanks.
4. Pump water pill off bottom to dissolve any un-mixed additive.
5. Before you pump the Hi/Low vis pills, confirm with the mud engineer that no additional weighting agents have been used. This may require adjustment of the flow rate to avoid over pressuring the seals.
6. Attempt to turn on the tool by bringing the flow up as fast as possible up to maximum drilling flow.
7. Attempt to turn on the tool using conventional techniques like recycling the pumps, surging the drill pipe etc.
8. Start at minimum flow and keep increasing the flow rate in five equal increments up to reaching maximum drilling flow

4.3 Shock & Vibration

Too much shock and vibration can be destructive to all BHA components and needs to be actively managed to avoid costly tool damage or, in extreme cases, parts left in hole. All well planning must include a plan to deal with high shocks and stick-slip. If experience from offset wells shows that high shocks and vibration are likely to be a problem, consult the client at an early stage. Create a clear action plan before the job begins, with agreement on the actions to be taken if shocks become excessive. There will be some occasions where excessive shocks can never be completely eliminated, and the best option may be to trip out of hole. Extreme shocks can damage all BHA components including MWD/LWD tools, bits, stabilizers, collars and BHA rotary shouldered connections. Shocks off bottom are of equal importance and must be managed in the same way as drilling shocks. Shock and vibration management should be promoted as good drilling practice, as well to make sure that the tool operates in the most favorable environment.

Active management of shocks and vibration requires that the problem be recognized, and then the appropriate action taken.

Low level shocks over a long period of time can be as dangerous to the tool as high-level shocks over a short period of time. Therefore, when shocks are at shock level 1, you must monitor the length of time at that risk level. If the shock risk level reaches level 3, you must take immediate action to mitigate the shocks. Accumulated time of shock at level 3 greater than 30 minutes is exceeding the tool specifications. The MWD tool will not see all of the shock being experienced by the tool. The crew should also be aware of other indicators of downhole shock and vibration. Under excessive stick-slip conditions, the rig's top drive will often be heard to strain, as the surface RPM and torque exhibits low frequency oscillations. ROP can be seen to drop in some severe cases of stick-slip.

When the shock levels are exceeded, the crew needs to inform the client and make sure that action is taken as soon as possible. The first step in management of the downhole shock and vibration environment is to change the surface drilling parameters. Often a fine balance between surface RPM and WOB will be required to reduce the shock levels. Ideally changes to RPM and WOB can be made while the bit is still on bottom but often the bit needs to be picked off bottom and the surface RPM reduced to zero to dissipate all the energy from the system. The new drilling parameters can then be selected, and drilling resumed.

5 Required End of Run Data

After completion of the job the Directional Driller at the wellsite is required to send in his final deliverables to their Directional Drilling Coordinator. The Directional Drilling Coordinator is then responsible for sending the final deliverables to the XER Operations Coordinator. At a minimum this must include the following information:

- Final BHA
- Final Motor Report
- Master Copy Run Tracker, filled out with each run information

For any run that had a Service Quality issue and requires a Maintenance Finding Report (MFR), the following information is also required:

- Downlink tracking sheet
- A typed out, detailed description of the issues experienced
- Any documents that may support the suspected failure mode (Mud Report for suspected LGS out of specification for example)

6 Document Revision History

Revision	Date	Editor	Comments
1.0	14-Nov-17	M. Oswald	Initial Document Creation. Job Planning & Tool Preparation
1.1	31-Jan-18	M. Oswald	Addition of Job Execution section
1.2	25-Mar-18	M. Oswald	Addition of Fishing Diagrams
1.3	4-Dec-19	A. Grobbel	Add PowerDrive App info and update sections 3, 4 and 5
1.4	6-Mar-20	A. Grobbel	Add Real time d-points

Appendix 1 – Real-Time d-points:

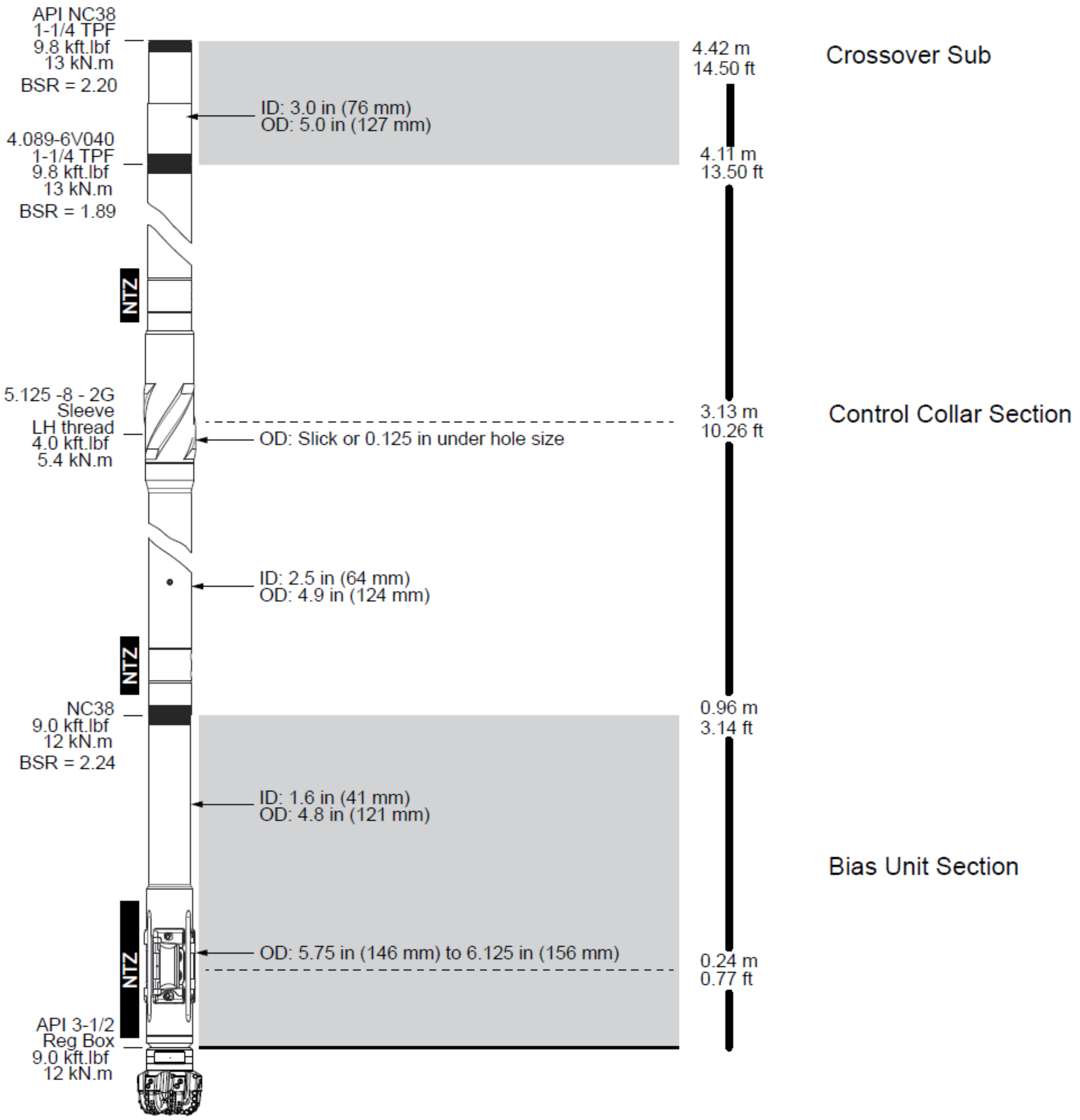
Name	Unit	Description
INCL	°	Inclination (continuous survey)
AZIM	°	Azimuth (continuous survey)
GT	mG	Total G
BT	nT	Total B (H)
RTSTAT	-	PD real time status word
STEER	-	Steering d-point
TFDS	°	Demand toolface
PRDS	%	Demand proportion
TFHI	°	Measured toolface (MTF or GTF) - high resolution
INCLQ	%	Effective steering proportion
AZIMQ	rpm	Lower Torquer RPM - Low Resolution
SHKRSK	-	Shock risk / severity
STKSLP	-	Stick-slip amplitude and frequency severity
AZIMLO	°	Azimuth - low resolution
TF	°	Measured toolface (MTF or GTF) - low resolution
SIG	-	Shorthop (S/H) receiver signal strength
SIGLO	-	S/H receiver signal strength - low resolution
SIGQ	-	S/H receiver status word
AGE	sec	Time elapsed since last data received by S/H receiver
DLNK	-	Last received downlink command
IH_TURN	%	Inclination Hold (IH) turn setting
PROPEFF	%	Effective steering proportion
IH_TRGT	°	Target IH
RTTOTSHK	-	Real time total shock
PCNTSTCK	-	Percent stuck
CCRPM	rpm	Control collar RPM
UTRPM	rpm	Upper torquer RPM
LTRPM	rpm	Lower Torquer RPM
GRAV	cps	Gamma ray average
GRUP	cps	Gamma ray up
GRLF	cps	Gamma ray left
GRDN	cps	Gamma ray down
GRRT	cps	Gamma ray right
GRAV_ext	cps	Extended gamma ray average
GRUP_ext	cps	Extended gamma ray up
GRLF_ext	cps	Extended gamma ray left
GRDN_ext	cps	Extended gamma ray down
GRRT_ext	cps	Extended gamma ray right
SS_AMPL	rpm	Stick-slip amplitude
SHK_AMPL	m/s^2	Shock amplitude
RTSTAT2	-	PD real time status word #2
RTSTAT3	-	PD real time status word #3
RTSTAT4	-	PD real time status word #4
POSSUM	%	Integral control term - PosSum
PDTEMP	°	PDCU temperature
AZI_TRGT	°	Target Azimuth

Appendix 2 – Fishing Diagrams:

475 PowerDrive Orbit

** This Fishing Diagram is for reference only, based on iron that has not been recut. The actual component measurements for the tool configuration to be run in the hole should be taken by the DD on location.

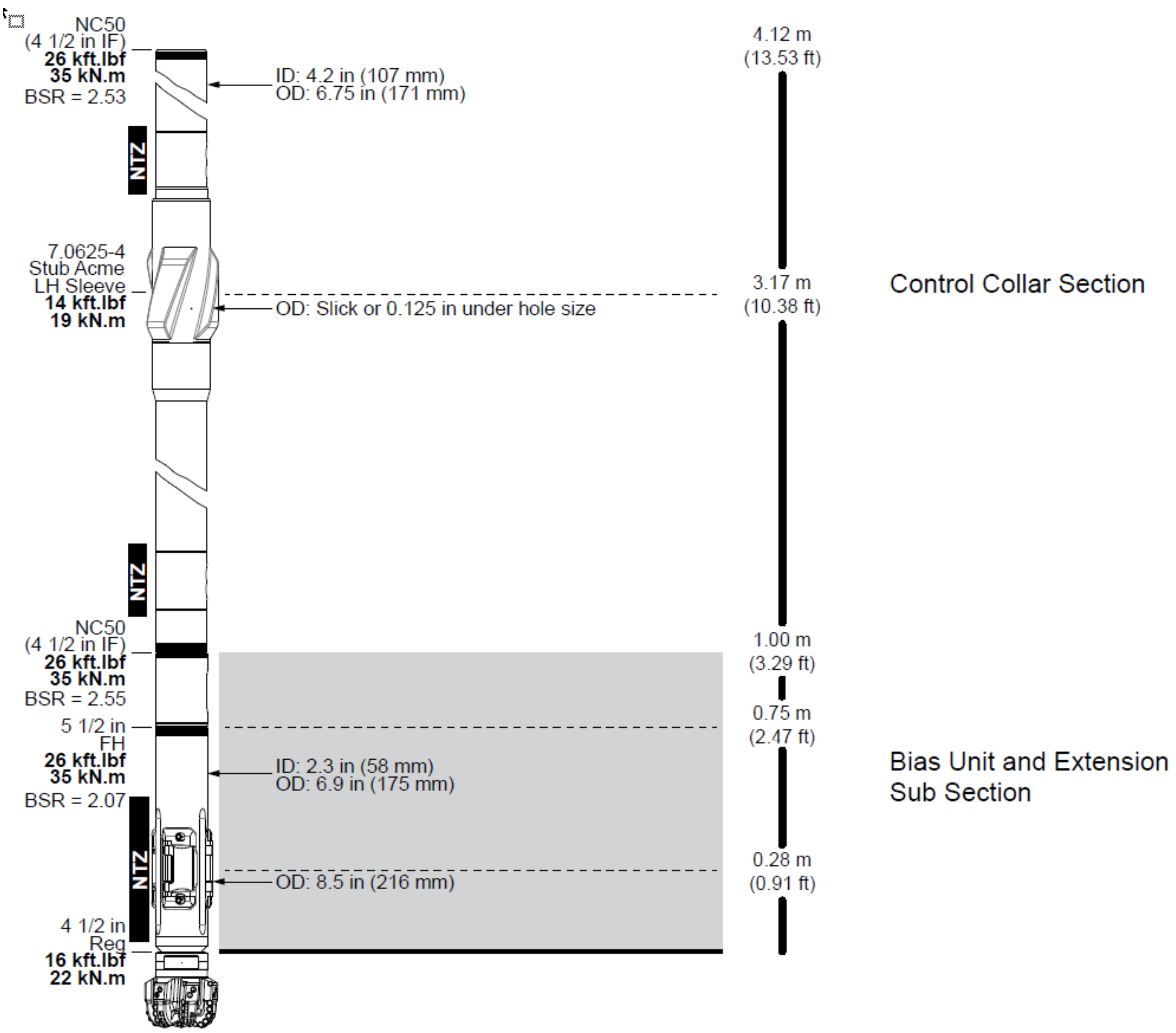
*** Do not place Tongs across anchor bolt sections or on any external bias unit components. These areas are noted NTZ (No Tong Zone) on the diagram below. When torqueing up the bit, be sure to grab above the bias unit clamp plate assemblies.



675 PowerDrive Orbit

** This Fishing Diagram is for reference only, based on iron that has not been recut. The actual component measurements for the tool configuration to be run in the hole should be taken by the DD on location.

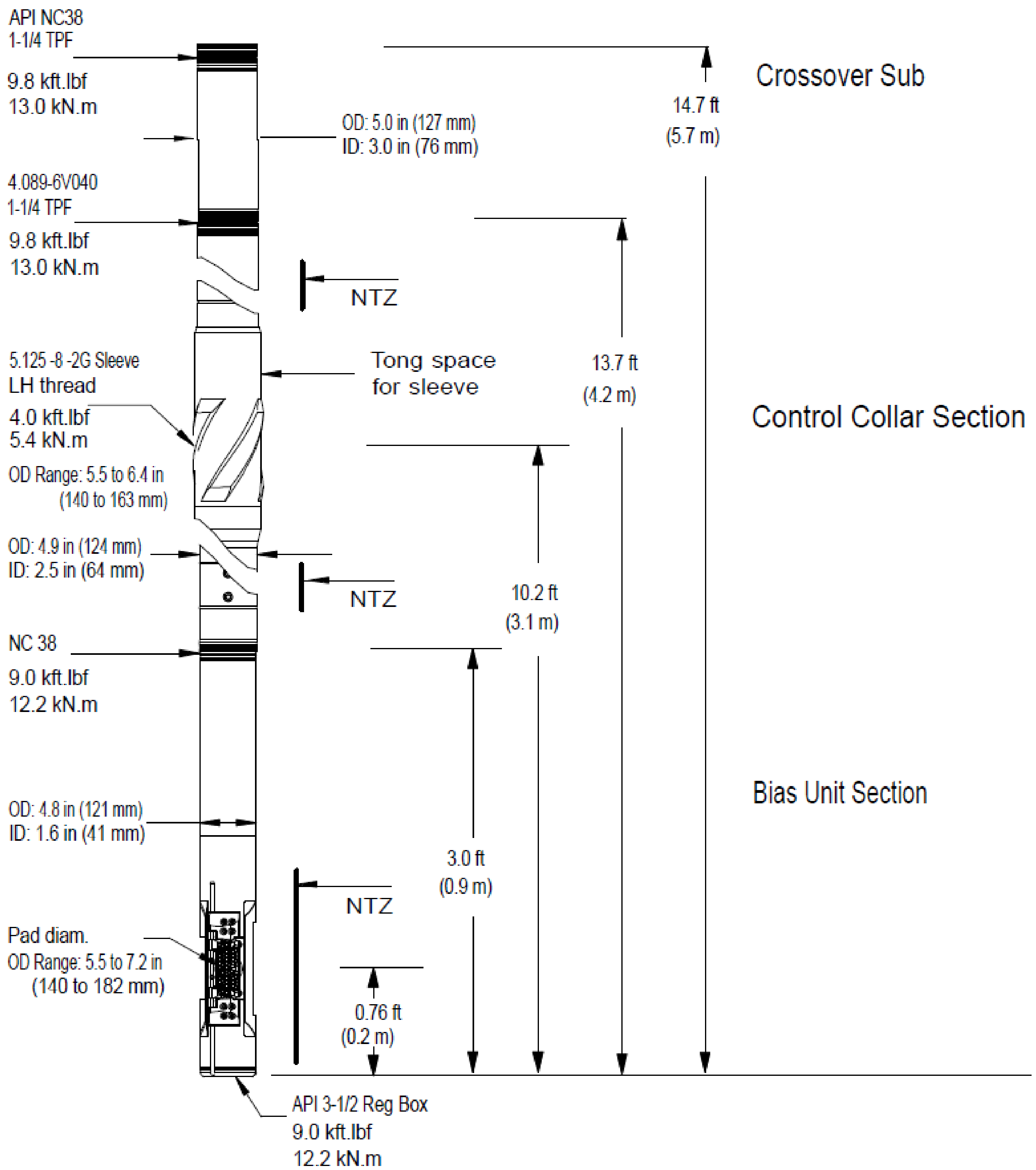
*** Do not place Tongs across anchor bolt sections or on any external bias unit components. These areas are noted NTZ (No Tong Zone) on the diagram below. When torqueing up the bit, be sure to grab above the bias unit clamp plate assemblies.



475 PowerDrive X6

** This Fishing Diagram is for reference only, based on iron that has not been recut. The actual component measurements for the tool configuration to be run in the hole should be taken by the DD on location.

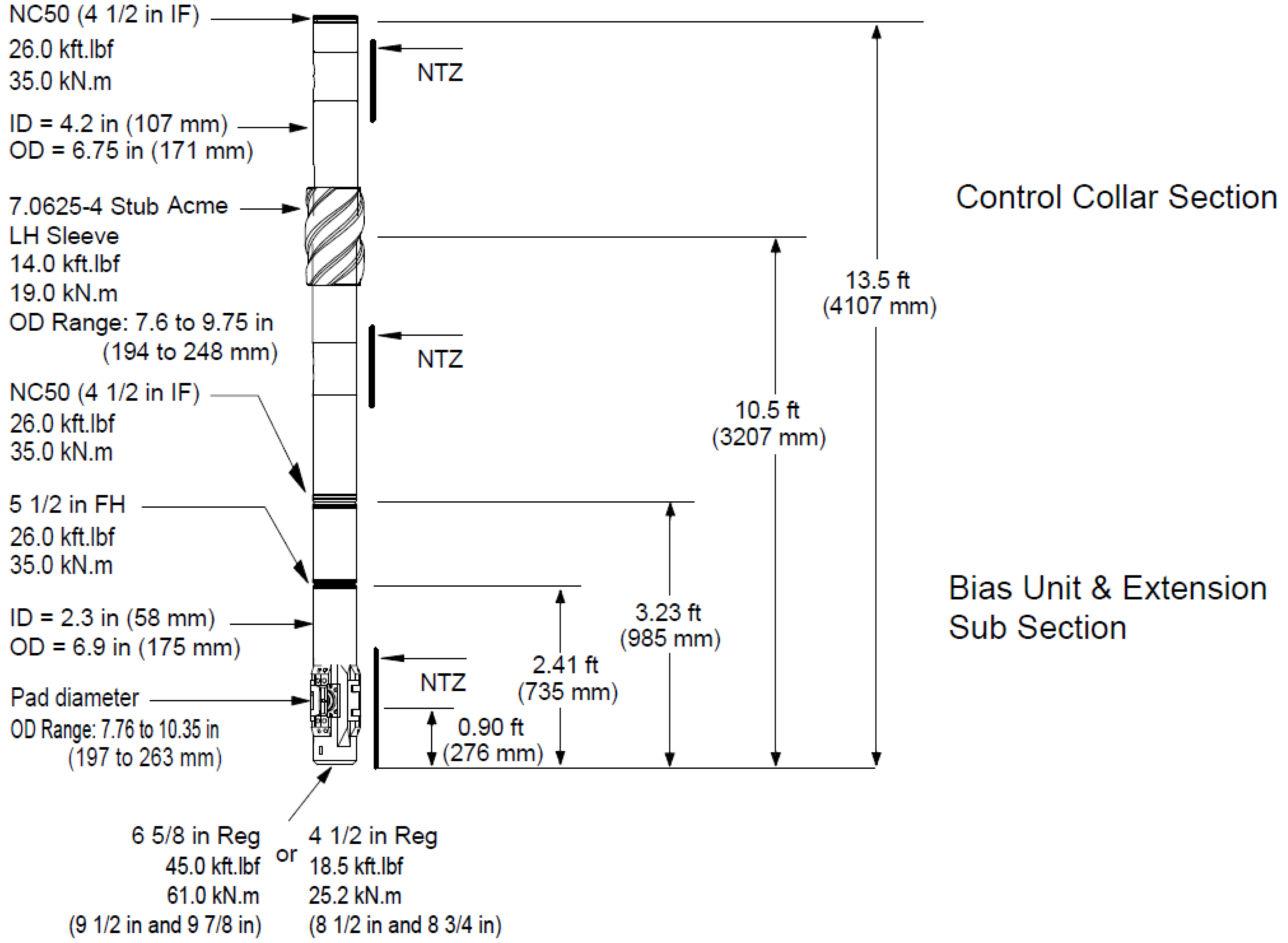
*** Do not place Tongs across anchor bolt sections or on any external bias unit components. These areas are noted NTZ (No Tong Zone) on the diagram below. When torqueing up the bit, be sure to grab above the bias unit clamp plate assemblies.



675 PowerDrive X6

** This Fishing Diagram is for reference only, based on iron that has not been recut. The actual component measurements for the tool configuration to be run in the hole should be taken by the DD on location.

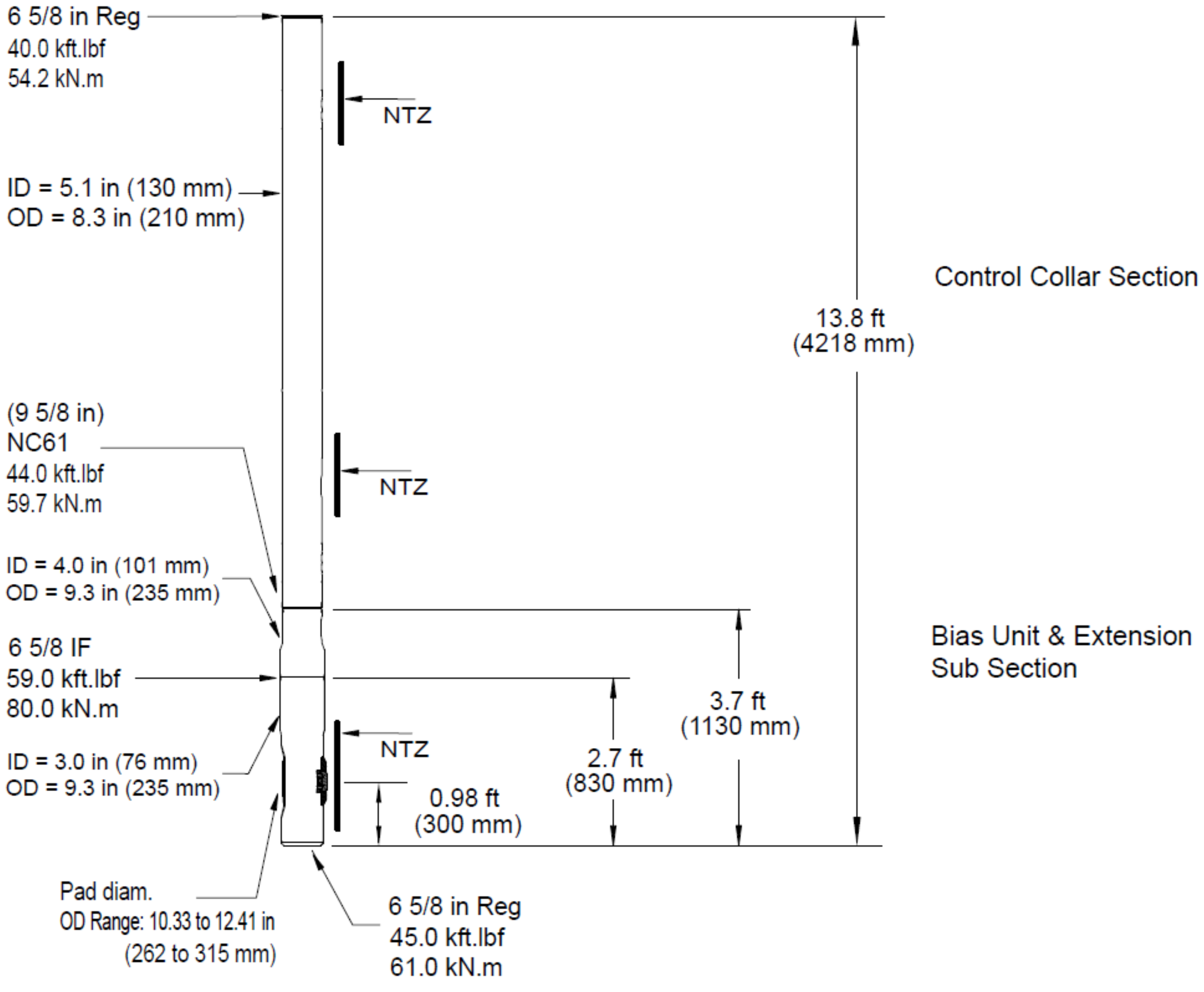
*** Do not place Tongs across anchor bolt sections or on any external bias unit components. These areas are noted NTZ (No Tong Zone) on the diagram below. When torqueing up the bit, be sure to grab above the bias unit clamp plate assemblies.



825 PowerDrive X6

** This Fishing Diagram is for reference only, based on iron that has not been recut. The actual component measurements for the tool configuration to be run in the hole should be taken by the DD on location.

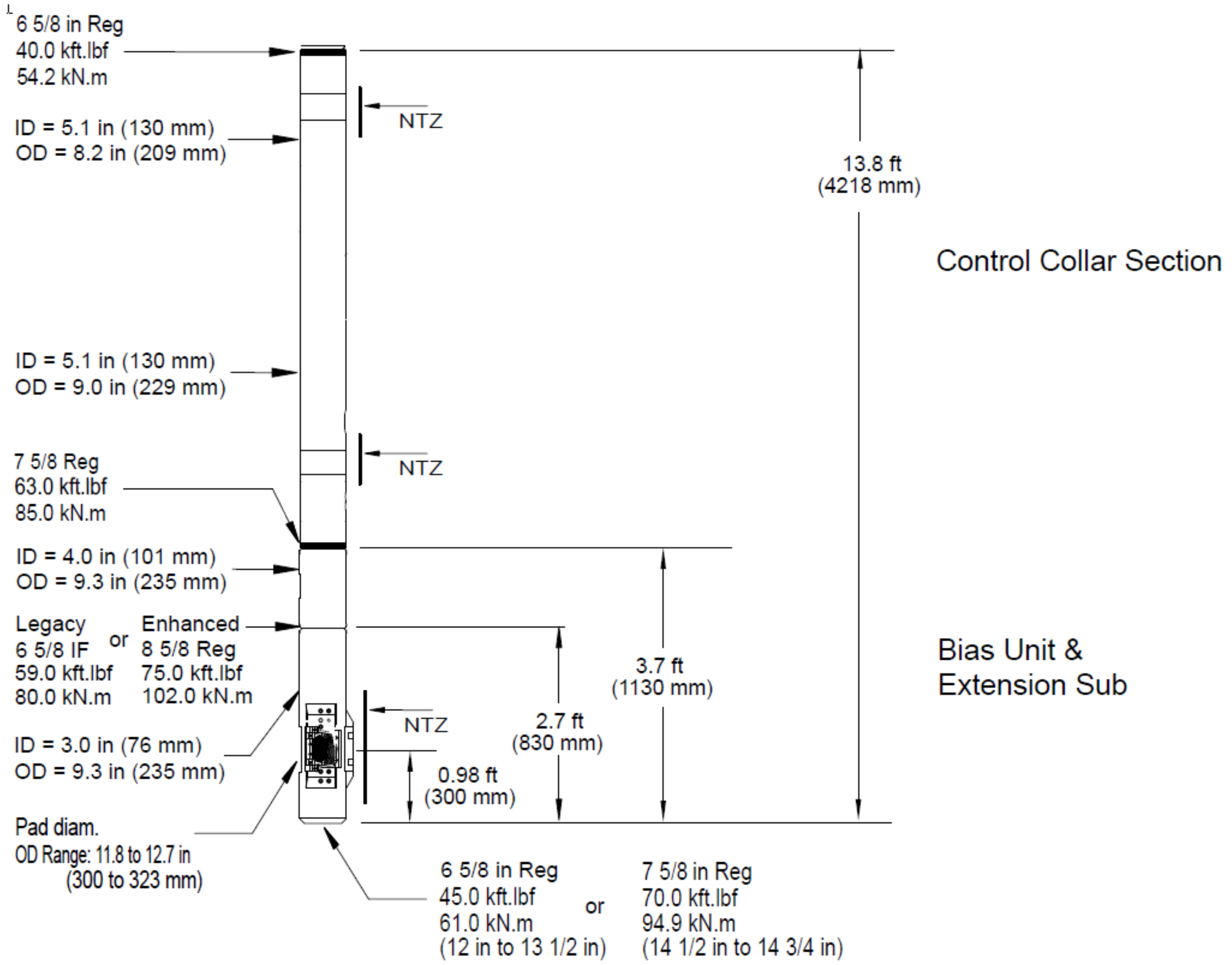
*** Do not place Tongs across anchor bolt sections or on any external bias unit components. These areas are noted NTZ (No Tong Zone) on the diagram below. When torqueing up the bit, be sure to grab above the bias unit clamp plate assemblies.



900 PowerDrive X6

** This Fishing Diagram is for reference only, based on iron that has not been recut. The actual component measurements for the tool configuration to be run in the hole should be taken by the DD on location.

*** Do not place Tongs across anchor bolt sections or on any external bias unit components. These areas are noted NTZ (No Tong Zone) on the diagram below. When torqueing up the bit, be sure to grab above the bias unit clamp plate assemblies.



1100 PowerDrive X6

** This Fishing Diagram is for reference only, based on iron that has not been recut. The actual component measurements for the tool configuration to be run in the hole should be taken by the DD on location.

*** Do not place Tongs across anchor bolt sections or on any external bias unit components. These areas are noted NTZ (No Tong Zone) on the diagram below. When torqueing up the bit, be sure to grab above the bias unit clamp plate assemblies.