PROCEEDINGS
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Analysis of Axial Oscillation System for Reducing Torsional Vibration during Drilling Horizontal Field A

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Abstract

The challenge of drilling in the instability of oil world price, requires innovation and technology applications to optimize drilling implementation. Torsional vibration (stick slip) are slowing down drilling operations and increasing drilling costs. Therefore, to mitigate these problems, the use of Axial Oscillation Generator System (AGT) is considered. AGT is a system commonly used to reduce downhole friction during drilling operations. Drilling parameter results are compared with offset well that had high stick slip.

The approach was based on qualitative research method, data processing was obtained from the drilling operation of the well A. The method was performed by evaluating the use of AGT in the Bottom Hole Assembly (BHA) series during the drilling operation. Such method mainly revolves around calculating some drilling parameters such as Torque, Weight on Bit (WOB), Rate of Penetration (ROP), Revolutions per Minute (RPM) and analysing the log results of the tools contained in the Rotary Steerable System (RSS) and Measurement While Drilling (MWD), as well as comparing it with offset well B, which had high stick slip.

The result of data analysis shows that the use of AGT tool on drilling of well A is more effective and efficient approximately 60% - 80%, evidenced by drilling parameter such as WOB and Torque that are reduced by around 30%, with downhole and surface RPM being relatively constant, and supported by log results that do not show any signs of stick slip. Furthermore, the use of AGT tool is compatible with BHA component (Mud Motor / RSS / MWD / LWD) as no problems was caused by AGT on the dynamic data of drilling well A. By comparing the two wells, the use of AGT on well A proved the ability to reduce the stick slip and increase weight transfer, thus reducing the cost of drilling.

The expected result of this analysis is a reference to the use of AGT tools as a component of BHA that can reduce the potential hazards of stick slip vibrations and expected to improve drilling efficiency in terms of time and cost.

Keywords: Drilling Optimization, Horizontal Drilling, Axial Oscillation System, Stick Slip, Drilling Performance.

Introduction

Today, with world WTI crude oil prices in 2016 – 2019 about $60 USD/bbl, Increasing productivity and efficiency of drilling operations are the problems in the oil & gas industry that must be addressed. Drilling operations at high inclination well (more than 30 degree) are usually found with several problems that cause in low drilling performance. As well as torsional vibration (stick slip), stick slip is a potentially damaging low frequency torsional vibrations where the bit comes to rest during low rpm and high WOB drilling parameters. The high cycling wind up Torque of the drill string when the bit is stationary can result in BHA configuration, connection and drill pipe over torque and damage. During stick slip cycle, the bit rpm will vary from zero to several times the top drive rpm. The bit and/or BHA and/or drill string and/or well condition could all be the cause of stick slip. Another problem is limited reach drilling, which means that the drilling connection is less able to transfer the amount of load to the bit, this due to several problems such as BHA design, the amount of friction between drilling connection and borehole, sinusoidal or helical buckling in pipelines, and accumulation of drag. Hence, an appropriate technology is needed to optimize drilling operations to total depth, the AGT technology is considered, which is placed on the BHA configuration. Therefore, the author will analyze the efficiency of using AGT tools on drilling horizontal well in field A by comparing the result of drilling operations of offset well without using AGT. Eventually, comparisons of efficiency levels are taken from the value of drilling performance.

Data

Well Review

The well data in this study using offshore well A data with the total depth of 8700' and a 90° slope. For the offset well data, it was obtained from well B with the total depth of 8900' and a 90° slope. Well B has been drilled several years before, with the distance approximately 130' from the well A.

Based on the MWD of offset well B, it was known from drilling mechanic log that at a depth of 6100' – 8900', the drilling operation in 6 1/8" section has a fairly severe stick slip that shown of 5 - 6 level severity (Figure 5) which caused in increased drilling parameter and potentially damaged one of MWD tool function. Therefore, based on these problems, the analysis was focused on well A and B drilling operations 6 1/8” section by taking the data such as the use of BHA configuration, Rate of Penetration (ROP) parameter, Weight on Bit (WOB) parameter, Torque parameter, Revolution per Minutes (RPM) parameter, and Torsional Efficiency Monitor (TEM) & Drill string Dynamic Sensor (DDS) log data.

Following (Table 1) are details of well B 6 1/8” section that was used for comparison and (Table 2) are details of Well A 6 1/8” section that was used for research object.

Tool Description

AGT is a system that used to reduce downhole friction during drilling operations. With the AGT sizes from 1 11/16 "to 9 5/8" outside diameter (OD), this tool is often used mainly on directed and horizontal drilling. Features and benefits of AGT:

- Gentle oscillation of the BHA reduces friction and dramatically improves weight transfer.
- No impact force to downhole tools
- Prevents weight stacking and allows.
- Excellent tool face control.
- Multiple placement possibilities.
- Self-operating tool.
- Increased sliding ROP.
- Field proven to work with RSS.
- Compatible with all MWD systems with pre-job planning
- Decreased lateral and torsional vibration.
- Extended bit life.
- High efficiency and reliability.
- Saves time and drilling costs.

The AGT system consist of 3 subassemblies (Figure 1):

- Power Section
- Valve and Bearing Section
- Shock Tool

The power section subassembly is a combination of a rotor inside a stator (Figure 2) that drives the valve section, producing pressure pulses in the system. These pulses activate the shock tool then creating axial motion. It is the axial motion of the shock tool that breaks static friction.

The unique valve system is the heart of the tool (Figure 3), converting the energy available from the pumped fluid into a series of pressure fluctuations. This done by creating cyclical restrictions through the pair of valve plates. The valve opens and closes with the result that the total flow area (TFA) of the tool cycles from maximum to minimum. At minimum TFA, the pressure is high. At maximum TFA, the pressure is low.

The frequency of these pressure pulses is directly proportional to the flow rate. The size of the valve plates configured based on operational parameters to optimize performance and ensure that the pressure drop is always within specification.

Composed of the power section, valve and bearing section, the FRT creates pressure pulses. In order to transform this hydraulic energy into a useful mechanical force in jointed pipe operations, a shock tool is placed above the FRT in the BHA or drill string.

The shock tool contains a sealed mandrel which is spring loaded axially (Figure 4). When internal pressure applied to the shock tool, the mandrel extends due to pressure acting on the sealing area of the tool, also known as the Pump Open Area (POA). If the pressure is removed, the springs return the mandrel to its original position.

When used directly above the FRT, the pressure pulses cause the shock tool to extend and retract, producing an axial oscillation. The AGT may be positioned anywhere in the drill string to focus energy where it will be most effective.

There are 2 main considerations for using the AGT:

- Increased in standpipe pressure (SPP)
  The increase that is used by AGT approximately 500-600 psi from the original SPP without using AGT.
- There is no the thru ID
  During drilling it cannot apply tools that have to pass through the thru ID, such as the use of wire line tools.

Result and Discussion

Torque Analysis

Stick slip is the related problem to the Torque parameter. Therefore, in this study Torque was calculated according to the BHA configuration along the depth. By calculating the actual torque of the well B, it can be found the coefficient value (μ) of well B, then the value of μ B can be used in calculating the original Torque well A. Each well was used 2 BHA configuration, in which (Table 3 & 4) are BHA configurations of well B and (Table 5 & 6) are BHA configurations of well A.

By using the Torque formula (Eq.1) and based on each BHA configuration that was used in such a way. Then for well B, the actual Torque calculation for BHA #1 was 9000 ft-lbs that used μ of 0.27. Whereas the actual Torque calculation for BHA #2 was 14000 ft-lbs that used μ of 0.33. By the result of offset well μ, the Torque calculation for BHA #1 of well A by using μ of 0.27, the Torque result was 9360 ft-lbs. And BHA #2 of well A by using μ of 0.33 the Torque result was 17146 ft-lbs.

AGT Placement

Determination of AGT placement behind the bit is to optimize the AGT effect on reducing Torque, by input the well A trajectory data (Table 7), the BHA configuration that will be used (Table 5 & 6), and several parameters of drilling planning data (Table 8). The special software processed 6 AGT placement simulations at BHA (Figure 6). Table 9 shows that 1st rank the most effective use of AGT was a 1129' behind the bit, it will reduce of torque approximately 30% of the actual torque without using AGT. Followed by the 2nd rank of effectiveness was 1723' behind the bit, even though the reduction in Torque is greater than the first order, but the effectiveness when drilling operation up to TD is not as good as the first rank.

In a field application, drilling well A 6 1/8" section was started from 6200' – 8696' by using AGT plus size 4 ¾". In which the AGT at BHA #1 was placed at a distance of 1211' behind the bit and BHA #2 at a distance of 1248' behind the bit.

Downhole Data Analysis

Drilling Performance

Table 10 details the parameter result of the use AGT in drilling well A that was compared to the parameter drilling well B (Non-AGT) which had full of stick slip problems. Comparisons are according to the use of BHA #1 from 6100' – 6600' and BHA #2 from 6600' – 8900' between well A and B.

Figure 7 shows the result of ROP comparison. The well B with severity stick slip approximately 4 – 6 level, the use of RSS & Motor, on BHA #1 with surface RPM approximately 65 rpm only reached ROP 26 ft/hr and BHA #2 surface RPM approximately 135 rpm only reached ROP 52 ft/hr. Whereas by AGT application has improved the ROP on well A drilling operation, BHA #1 with mud motor application, average RPM approximately 55 rpm, ROP when sliding and rotating improved approximately 20%, with an average of 32.8 ft/hr. BHA #2 with RSS application, average RPM approximately 100 rpm, ROP improved approximately 7%, with an average of 56 ft/hr. This case has proved that the use of AGT with mud motor application was more effective when sliding, in which AGT can reduce some friction so that it can increase the ROP.

Figure 8 shows the comparison between RPM surface and downhole. The first comparison on BHA #1, for well B with RPM surface 65 rpm, the downhole RPM fluctuation range that occurred was widely enough, approximately 120-180 rpm. Whereas by AGT application on well A with RPM surface 55 rpm, the downhole RPM fluctuation range that occurred was tighter, approximately 280 – 290 rpm. This significant differences between RPM surface and downhole of well A or B were due to the addition of sub-surface motor RPMs. Next on BHA #2, for well B with RPM surface 135 rpm, the downhole RPM fluctuation range that occurred was widely enough, approximately 170-280 rpm, this case was indicated due to the addition of motor RPM and the effect of stick slip problem. Whereas by AGT application on well A with RPM surface 100 rpm, the downhole RPM range did not occur, which was smooth with average RPM approximately 100 rpm, this due to the use of RSS that only used RPM surface that sourced from Top Drive System (TDS) or Rotary Table which made similar RPM between surface and downhole, and was indicated the absence of additional stick slip problems.

Figure 9 shows the result of WOB comparison, The well B in accordance to BHA #1 configuration along 6665' with 80° slope, WOB was required of 12000 lbs, and in accordance to BHA #2 configuration along 8900' with 90° slope, WOB was required of 13000 lbs. Whereas by the AGT application during drilling operation on well A, BHA #1 configuration along 6593' with 80° slope has reduced approximately 17% of offset well, with an average WOB was required of 10000 lbs. Also on BHA #2 configuration along 8696' with 90° slope has reduced approximately 46% of offset well, with an average WOB was required of 7000 lbs. The reduction of 46% has proved that AGT application with RSS on the well A BHA #2 was effectively enough in optimizing weight transfer to the bit, with the lighter WOB and the optimal weight transfer, then the bit can maximize ROP.

Figure 10 shows the Torque comparison, the drilling on well B BHA #1 has required Torque of 9000 ft-lbs, and on BHA #2 with full stick sip problem has required Torque of 14000 ft-lbs. Whereas by AGT application on well A drilling operation, reduction Torque has occurred on BHA #1 approximately 11% of offset well with average Torque of 8000 ft-lbs, and BHA #2 reduction torque has occurred approximately 18% of offset well with average Torque of 11500 ft-lbs. This case has proved that AGT application on BHA #1 and #2 could run effectively for reducing torsional vibration.

The AGT Effect on Drilling Torque (Well A)

In accordance with the Torque analysis calculations before, Table 11 details the result of the reduction factor effect of using AGT between the result of pre-job planning calculation and actual Torque. Where the AGT application on BHA #1 has reduced Torque about 15% from the well A Torque calculation. Whereas on BHA #2 has reduced Torque about 33%. This case has proved that on the step of determining FRS placement with the distance of 1129' behind the bit it would reduce about 30% from the required Torque without FRS application.

Drilling Vibration Log Result

From the drilling DDS log of well B (Figure 13), the AVG log is the average value of magnitude, in this case, the axis of **x** and **y** at a depth 6100' – 8900' has demonstrated that the level vibration was highly enough which was signed by red color at some sections, so that it was indicated stick slip problem. However, when was seen from the Peak log that is the maximum fluctuation value of average magnitude, in which the axis of **x** and **y** was indicated that the bit rotation was smoothly enough and categorized as a low vibration that was signed by green color along the section. So it can be concluded that from the log AVG & Peak there has occurred severe stick slip problem which was signed by high average stick slip value, without the low average of fluctuation. Likewise, when was seen from RPM of Geo Pilot (GP), along the depth approximately 2700' has occurred severe stick slip which was signed by high RPM values and fluctuations. From the RPM GP log, by using the torsional efficiency (TE) formula (Eq. 2), table 12 is the result of average efficiency calculation of well B drilling operation. Basically, the indication of full stick slip is shown on the delta RPM reaches more than twice of average RPM that produces the negative value of TE. In this case, drilling at a depth of 6100' – 6225', with the delta RPM approximately 225 rpm, and average RPM reached 110 rpm, the result of TE calculation was a -2%, which means that the drilling of well B in this depth has occurred full variations of stick slip with torsional efficiency rate 0%.

Whereas by AGT application on well A, the log AVG & Peak from DDS log (Figure 14) has demonstrated that the axis of **x** and **y** at a depth 6200' – 8696' has had smooth bit rotation which was signed by green color along drilling the well A. Also was proved on the RPM GP log, table 13 is the result of average efficiency calculation of well A drilling operation. At a depth of 6200' – 6593' by mud motor with AGT application, the delta RPM approximately 200 rpm, and average RPM reached 260 rpm. And at a depth 6593' – 8696' by RSS with AGT application, the delta RPM approximately 40 rpm, and average RPM reached 100 rpm. Therefore, the result of TE calculation has demonstrated that the use of AGT in drilling well A 6 1/8" section along 2400' more efficient approximately 60% - 80%, without stick slip problem, with RPM variation that relatively smooth.

Conclusions

After analyzing the use of AGT in the well A drilling operation, so it can be concluded as follows:

1. The use of AGT with Mud Motor when sliding, can reduce some of friction during drilling operation, so that it can improved ROP and reduced the rig time.
2. The use of AGT with RSS in drilling operations is very effective in optimizing weight transfer to the bit, with enable less weight requirement to achieve performance.
3. The use of AGT with RSS in drilling operations can produce drilling parameter such as WOB, Torque, RPM were lower and relatively constant.
4. This case has proved that in the phase of pre-job planning by the special software could run accurately for reducing Torque.
5. The use of AGT was compatible with BHA components (Mud Motor / RSS / MWD / LWD) that was demonstrated with the absence of problems that was caused by AGT on downhole dynamic drilling data.

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Appendix

Eq. 1 $$T = \frac{OD\ Wdp\ L\ \mu\ Sin\theta}{24}$$

Where:

T = Torque, ft-lbs.
OD = Outer Diameter of pipe, Inch.
Wdp = Weight Drill Pipe, ppf.
L = Length pipe, ft.
μ = Coefficient.
θ = Dip Angle of Hole, Degree

Eq. 2 $$TE = \left(1 - \frac{(Max\ RPM - Min\ RPM)}{2 * Mean\ RPM}\right) * 100\%$$

Where:

TE = Torsional Efficiency, Percent.
RPM = Revolution per Minutes.

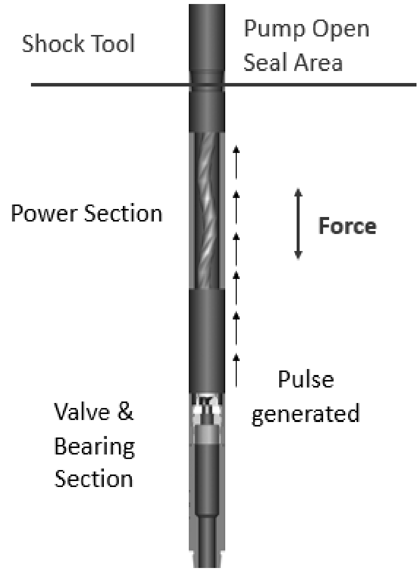

Figure 1 – Axial Oscillation Genarator System

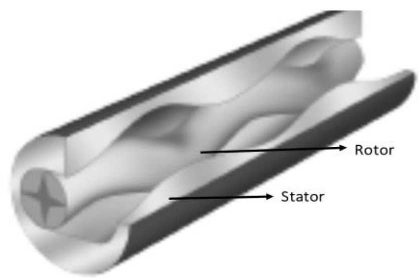

Figure 2 – Power Section of AGT

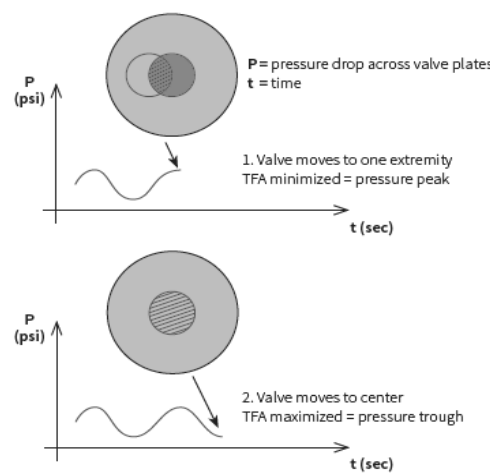

Figure 3 – Valve Sytem of AGT

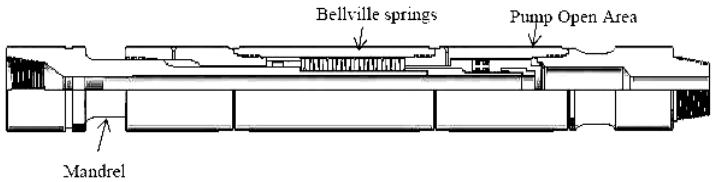

Figure 4 – Shock Tool of AGT

Level	Log	Stick slip Condition	On Bottom	Off Bottom
0		Normal		
1		Normal		
2		Torsional Oscillation		
3		Torsional Oscillation		
4		Torsional Oscillation		✓
5		Stick Slip	✓	
6		Stick Slip		
7		Backwards Rotation		

Figure 5 – Vibration Log Severity (well B)

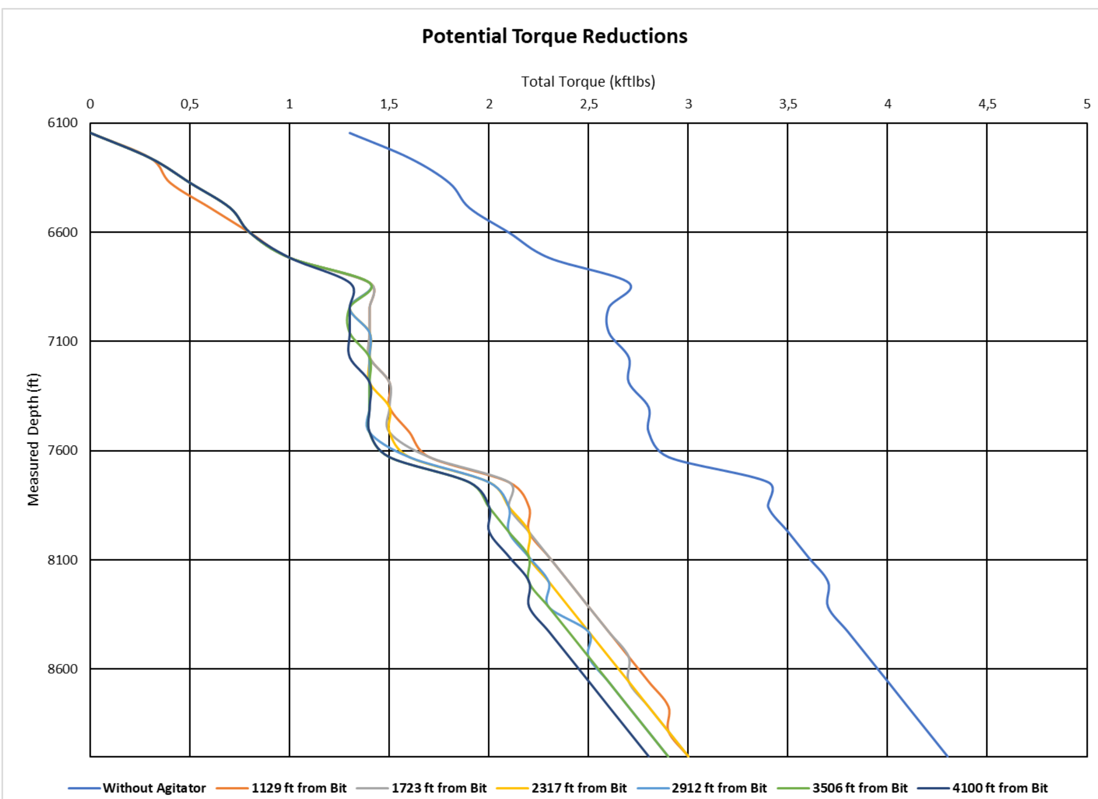

Figure 6 – Special Software result

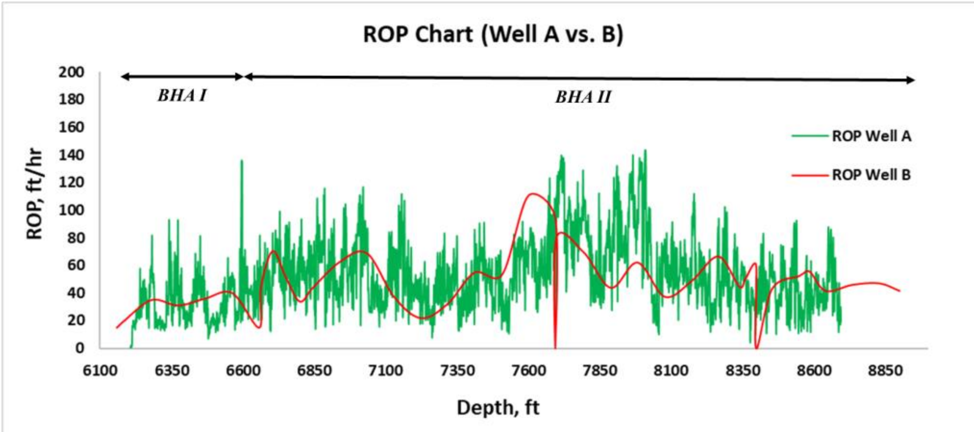

Figure 7 – ROP Chart (Well A vs. B)

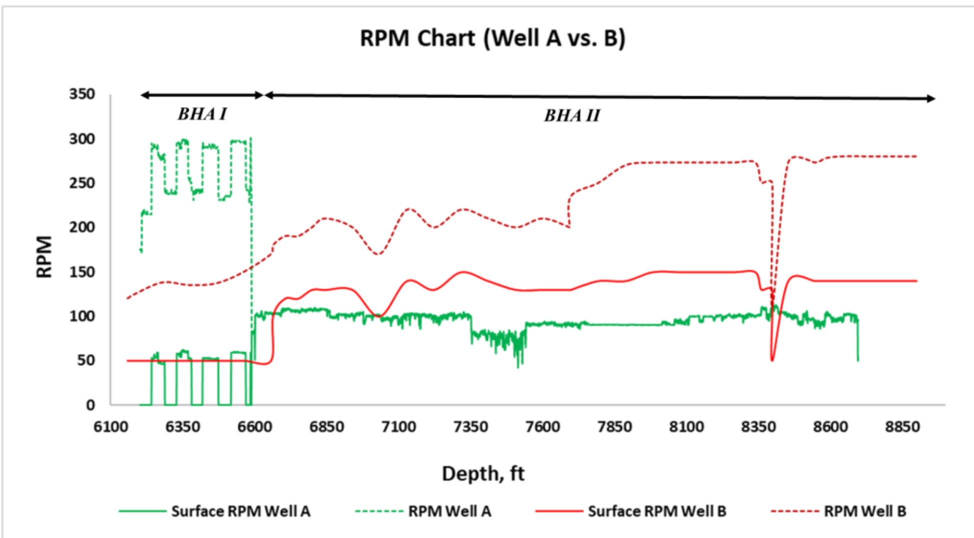

Figure 8 – RPM Chart (Well A vs. B)

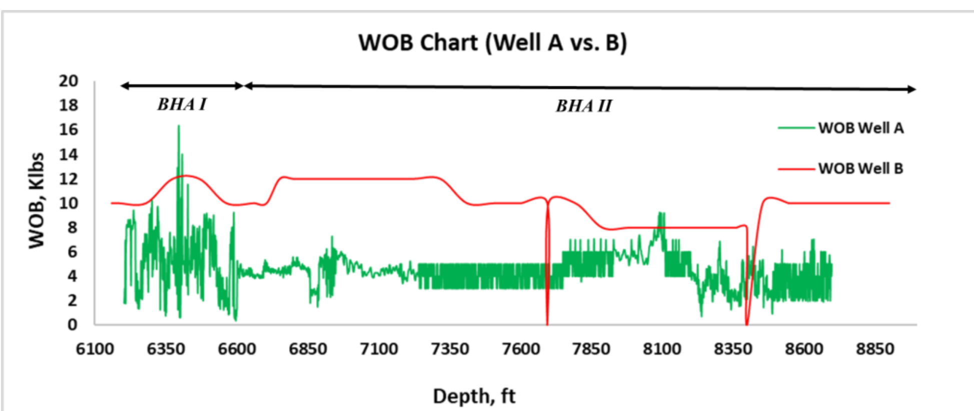

Figure 9 – WOB Chart (Well A vs. B)

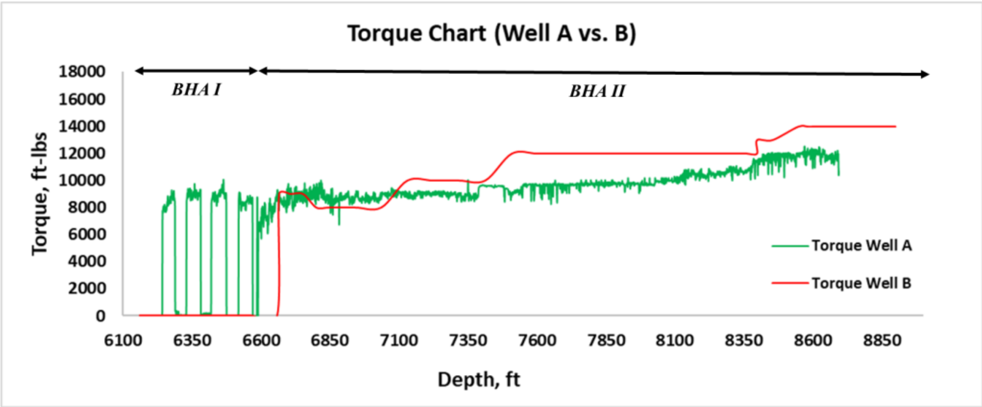

Figure 10 – Torque Chart (Well A vs. B)

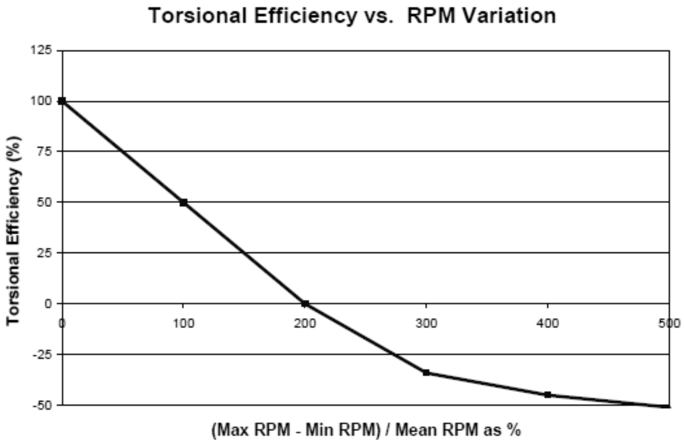

Figure 11 – Torsional Efficiency chart

Severity Level	Torsional Efficiency	(Max RPM- Min RPM)/mean RPM as a %	Notes
Low	100 - 50%	0 - 100%	
Medium	50 - 25 %	100 - 150%	
High	25 - 0%	150 - 200%	Onset of full-stall stick-slip
Full-blown	<0 %	200% +	

Figure 12 – Severity Level of Real Time Torsional Efficiency Data

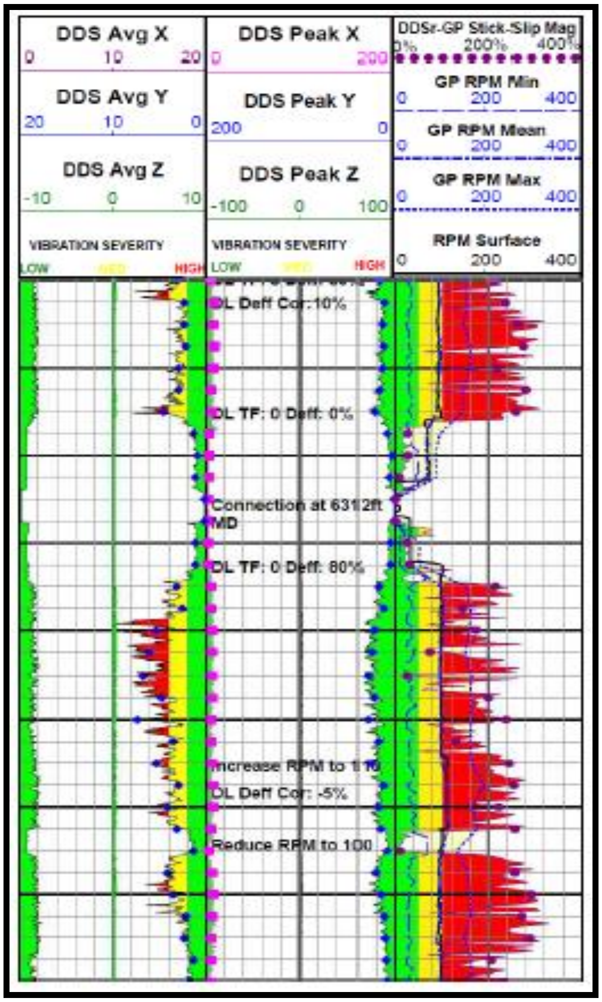

Figure 13 - Vibration Log (Well B)

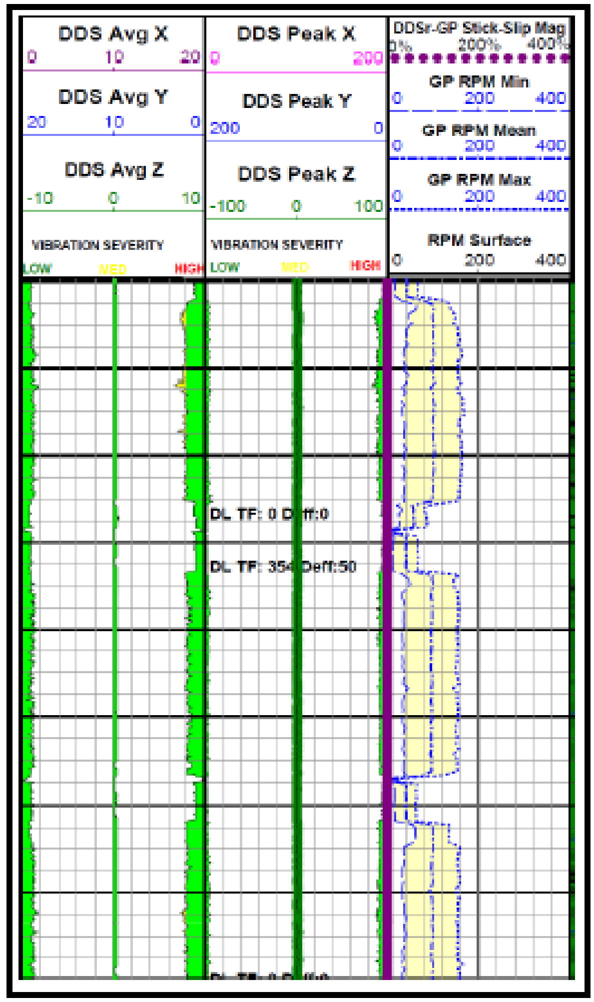

Figure 14 - Vibration Log (Well A)

Table 1 – Well B Profile (Offset Well)

Hole Size (in)	BHA	MD in (ft)	Md Out (ft)	TVD In (ft)	TVD Out (ft)	Inc In (deg)	Inc Out (deg)	Azi In (deg)	Azi Out (deg)
6.125	#1	6155	6665	5684	5815	64,93	78,16	51,08	52,36
	#2	6665	8900	5815	5847	78,16	89,34	52,36	50,36

Table 2 – Well A Profile

Hole Size (in)	BHA	MD in (ft)	Md Out (ft)	TVD In (ft)	TVD Out (ft)	Inc In (deg)	Inc Out (deg)	Azi In (deg)	Azi Out (deg)
6.125	#1	6200	6593	5708	5779	68,78	85,10	3,24	2,02
	#2	6593	8696	5779	5795	85,10	89,71	2,02	22,21

Table 3 – BHA #1 well B

BHA	Components	Component Details	Jts	OD/ID (In)	Weight (ppf)	Length (ft)	Cum Length (ft)
#1	Sub	X/O (DODI)	1	5.000/2.000	46,84	3,5	3,5
	Drill Pipe	168 x 3 1/2" DP (DODI)	168	3.000/3.000	16,88	5116,5	5120
	Heavy Weight	7 x 3 1/2" HWDP (DODI)	7	3.000/2.000	29,7	212,7	5332,7
	Accelerator	4 3/4" Accelerator, #1421-1068	1	4.750/2.000	29,7	32,7	5365,4
	Heavy Weight	5 x 3 1/2" HWDP (DODI)	5	3.000/2.000	29,7	151,2	5516,6
	Jar	4 3/4" Jars, #1420-1690	1	4.750/2.000	43,9	30,2	5546,8
	Heavy Weight	4 x 3 1/2" HWDP (DODI)	4	3.000/2.000	29,7	122,6	5669,4
	Sub	4 3/4" PBL Sub, #WES475BP071	1	4.750/2.000	46,84	7,5	5676,9
	Sub	Filter Sub, #10638303	1	4.750/-	46,84	6	5682,9
	Sub	Float Sub, #10631357	1	4.750/2.000	46,84	2,7	5685,6
	Drill Collar	NMDC, #P719	1	4.750/2.000	48,2	29,3	5714,9
	Stabilizer	5 7/8" String Stabilizer, #10167373	1	4.750/2.000	50,96	5	5719,9
	Sub	Stop Sub, #10432073	1	4.750/2.000	46,84	2,5	5722,4
	MWD	SDN, 10517766	1	4.750/1.000	40,25	17,3	5739,7
	MWD	BCPM, #10625219	1	5.000/1.380	53,7	11,1	5750,8
	Stabilizer	5 7/8" Mod Stabilizer, #10327038	1	5.000/2.250	48,2	3,3	5754,1
	MWD	On track, #10567872	1	4.750/1.340	60,39	19,9	5774
	Mod Motor	4 3/4" Modular Motor, #10232148	1	4.000/3.000	46,84	24,7	5798,7
	MWD	Auto Track Steering Unit, #10411776	1	5.240	48	10	5808,7
	Bit	6 1/8" PDC Bit, Hughes, HCD 406, #7900844	1	6.125	54,37	0,9	5809,6

Table 4 – BHA #2 well B

BHA	Components	Component Details	Jts	OD/ID (In)	Weight (ppf)	Length (ft)	Cum Length (ft)
#2	Sub	X/O (DODI)	1	5.500/2.250	46,84	3,5	3,5
	Drill Pipe	171 x 3 1/2" DP (DODI)	171	3.500/3.000	16,88	5402,6	5406,1
	Heavy Weight	7 x 3 1/2" HWDP (DODI)	7	3.500/2.250	29,7	212,7	5618,8
	Accelerator	4 3/4" Accelerator, #1421-1068	1	4.750/2.250	29,7	32,7	5651,5
	Heavy Weight	5 x 3 1/2" HWDP (DODI)	5	3.500/2.250	29,7	151,2	5802,7
	Jar	4 3/4" Jars, #1420-1690	1	4.750/2.250	43,9	30,2	5832,9
	Heavy Weight	4 x 3 1/2" HWDP (DODI)	4	3.500/2.250	29,7	122,6	5955,5
	Sub	4 3/4" PBL Sub, #WES475BP071	1	4.750/2.190	46,84	7,5	5963
	Sub	Filter Sub, #10638303	1	4.750/-	46,84	6	5969
	Sub	Float Sub, #10631357	1	4.750/2.190	46,84	2,7	5971,7
	Drill Collar	NMDC, #P-719	1	4.940/2.750	48,2	29,3	6001
	Stabilizer	5 7/8" String Stabilizer, #10167373	1	4.750/2.250	50,96	5	6006
	Sub	Stop Sub, #10432073	1	4.940/2.250	46,84	2,5	6008,5
	MWD	SDN, 10427460	1	4.750/1.875	40,25	17,3	6025,8
	MWD	BCPM, #10105003	1	5.000/1.380	53,7	11,1	6036,9
	Stabilizer	5 7/8" Mod Stabilizer, #10327038	1	5.000/2.250	48,2	3,3	6040,2
	MWD	On track, #10590372	1	4.750/1.340	60,39	20,2	6060,4
	Mod Motor	4 3/4" Modular Motor, #10173773	1	4.874/3.421	46,84	24,7	6085,1
	MWD	Auto Track Steering Unit, #10411776	1	5.240/-	48	10	6095,1
	Bit	1/8" PDC Bit, Smith, MSi613WPX, #JX9753	1	6.125/-	54,37	0,7	6095,8

Table 5 – BHA #1 well A

BHA	Components	Component Details	Jts	OD/ID (In)	Weight (ppf)	Length (ft)	Cum Length (ft)
	Sub	Crossover Sub 3-1/2 IF P x HT55 B S/N S-2814128	1	4.750/2.750	40,15	3,5	3,5
	Drill Collar	1 x 4 3/4" Drill Collar S/N 21563-18	1	4.750/2.250	46,7	30,5	34
	Jar	4-3/4"Drilling Jar S/N 080-47728	1	4.750/2.000	46,69	15,4	49,4
	Drill Collar	1 x 4 3/4" Drill Collar S/N 473025	1	4.750/2.250	46,7	29,7	79,1
	Sub	Crossover Sub XT39 P x 3-1/2 IF B S/N 2092-1001	1	4.750/2.700	40,88	2,7	81,8
	Heavy Weight	21 x 4" HWDP	21	4.000/2.563	29,7	644,5	726,3
	Drill Pipe	18 x 4" DP 18	18	4.000/2.800	21,84	564,4	1290,7
	Sub	Crossover Sub 3-1/2 IF P x XT39 B S/N E-0778	1	4.750/2.700	40,88	2,6	1293,3
	Friction Red	4-3/4" Agitator Jar S/N 170-1817489	1	4.750/2.000		12,1	1305,4
#1	Friction Red	4-3/4" Agitator S/N 0475-1481364	1	4.750/2.250	46,84	10,9	1316,3
	Drill Pipe	36 x 3-1/2" DP 36	36	3.500/2.438	16,88	1125,4	2441,7
	Sub	4-3/4" Downhole Screen S/N 11597809	1	4.750/2.250	46,84	7	2448,7
	MWD	4 3/4" HOC S/N 1116324	1	4.790/2.812	40,25	11,1	2459,8
	MWD	4 3/4" ADR Collar S/N 90494377	1	4.750/1.250	53,7	27,1	2486,9
	Drill Collar	4 3/4" PM Collar S/N 12396714	1	4.750/2.610	48,2	9,2	2496,1
	Stabilizer	5-7/8" Integral Blade S/N BBS98830	1	4.750/2.250	60,39	4,8	2500,9
	Sub	4-3/4" Float Sub S/N 11484796	1	4.750/2.250	47	2,4	2503,3
	Mod Motor	5" Sperry Drill Lobe S/N 11357183	1	5.000/3.120	48	23,3	2526,6
	Bit	6-1/8" PDC Smith Bit S/N JJ7656	1	4.750/1.500	54,37	0,7	2527,3

Table 6 – BHA #2 well A

BHA	Components	Component Details	Jts	OD/ID (In)	Weight (ppf)	Length (ft)	Cum Length (ft)
	Sub	5-1/2" X 4.778" - 21.9# 7" X 4" FH	1	5.500/4.778	23,77	31	31
	Sub	Cross Over Sub	1	4.750/2.000	49,69	3,5	34,5
	Drill Collar	4 3/4" Drill Collar	1	4.750/2.250	46,70	30,5	65
	Jar	4-3/4"Drilling Jar	1	4.750/2.000	49,69	15,4	80,4
	Drill Collar	4 3/4" Drill Collar	1	4.750/2.250	46,70	29,7	110,1
	Sub	Cross Over Sub	1	4.750/2.700	40,88	2,7	112,8
	Heavy Weight	4" HWDP	21	4.000/2.563	29,70	661,5	774,3
	Drill Pipe	4" DP	81	4.000/2.800	21,84	2532,8	3307,1
	Sub	Cross Over Sub	1	4.750/2.000	49,69	2,6	3309,7
	Friction Red	4-3/4" Agitator jar S/N 170-1817490	1	4.750/2.250	46,84	12,1	3321,8
	Friction Red	4-3/4" Agitator S/N 0475-1481364	1	4.750/2.250		10,8	3332,6
	Drill Pipe	3-1/2" DP 36	36	3.500/2.438	16,88	1125,4	4458
#2	Sub	4-3/4" Float Sub S/N 11484796	1	4.800/2.000	50,96	2,4	4460,4
	Sub	4-3/4" Downhole Screen S/N 12240789	1	4.750/2.250	46,84	7	4467,4
	MWD	4 3/4" HOC S/N 11293587	1	4.790/2.812	40,25	11,1	4478,5
	MWD	4 3/4" PWD 175C 30KSI S/N 90494378	1	4.750/1.250	47,90	9,1	4487,6
	MWD	4 3/4" CTN Collar 175C 30KSI S/N 90511255	1	4.750/1.250	50,50	10,9	4498,5
	MWD	4 3/4" ALD Collar 175C 30KSI S/N 90511255	1	4.750/1.250	45,50	14,2	4512,7
	MWD	4 3/4" HCIM Collar 175C 25KSI S/N 90494377	1	4.750/1.250	46,90	8,2	4520,9
	MWD	4 3/4" ADR Collar S/N 90494377	1	4.750/1.250	53,70	18,9	4539,8
	MWD	4 3/4" GM Collar S/N 12396724	1	4.750/2.610	48,20	9,3	4549,1
	Stabilizer	Inline Stabilizer (ILS) 175C 30KSI S/N CP 1540720	1	5.750/2.000	50,96	3,6	4552,7
	MWD	4 3/4" DM Collar S/N 11156485	1	4.750/2.610	48,20	9,2	4561,9
	RSS	Geo-Pilot 5200 XL S/N GP520TL195	1	5.875/1.125	45,13	16,5	4578,4
	Stabilizer	Turbo Back Stabilizer	1	6.062/2.000	49,69	1	4579,4
	Bit	6-1/8" PDC Smith Bit S/N JJ7656	1	6.125/1.500	54,37	0,7	4580,1

Table 7 – Trajectory well A

MD (ft)	INC (º)	AZ (º)	TVD (ft)	DLS (º/100ft)	MD (ft)	INC (º)	AZ (º)	TVD (ft)	DLS (º/100ft)
0	0.00	0.00	0	0.00	5830	50.83	2.84	5511	4.13
76	0.00	0.00	76	0.00	6112	66.30	3.18	5658	5.40
190	1.05	288.11	190	0.41	6252	70.78	2.24	5710	4.25
280	0.95	293.31	280	0.62	6347	75.15	1.41	5738	4.68
370	0.80	269.58	370	0.41	6440	78.63	1.44	5759	3.74
460	0.44	272.18	460	0.47	6535	83.06	1.66	5774	4.67
550	0.38	268.79	550	0.40	6578	84.62	1.70	5779	3.63
640	0.45	268.02	640	0.14	6672	87.62	3.72	5785	3.87
730	0.54	250.42	730	0.25	6766	89.74	4.51	5787	2.38
820	0.36	263.13	820	0.61	6861	90.55	4.45	5787	0.85
910	0.54	286.06	910	0.35	6956	90.80	3.91	5786	0.63
1000	0.37	322.77	1000	0.84	7050	90.06	4.82	5785	1.25
1210	0.75	235.26	1210	1.47	7144	88.77	7.64	5786	3.30
1330	0.60	330.23	1330	0.87	7238	89.00	10.41	5788	2.96
1420	0.28	66.97	1420	0.39	7332	87.46	11.52	5791	2.02
1510	0.48	160.15	1510	0.74	7426	89.87	13.69	5793	3.45
1600	0.62	160.07	1600	0.33	7520	89.44	14.89	5794	1.36
1720	0.13	282.33	1720	1.37	7614	88.70	17.58	5795	2.97
1840	0.25	343.39	1840	0.92	7707	89.50	19.86	5797	2.60
1960	0.21	114.94	1960	0.49	7802	90.98	20.54	5796	1.71
2286	10.03	168.20	2285	2.87	7809	91.08	20.57	5796	1.37
2663	21.32	169.50	2647	3.31	7877	91.96	20.84	5794	1.37
2946	21.74	167.62	2910	0.49	7897	92.22	20.92	5793	1.37
3229	21.55	166.08	3173	0.18	7991	91.05	20.75	5791	1.26
3513	19.58	160.43	3437	2.28	8086	89.19	20.54	5791	1.97
3797	10.66	157.37	3711	2.75	8179	87.59	19.60	5793	2.00
4080	7.18	112.01	3992	3.22	8274	88.38	18.60	5797	1.34
4364	10.60	45.64	4272	4.48	8368	90.67	18.78	5797	2.44
4626	16.55	21.12	4527	2.63	8463	91.23	19.69	5796	1.12
4909	25.48	9.24	4791	3.24	8558	90.55	19.96	5794	0.77
5267	36.29	2.95	5095	0.73	8652	89.26	21.49	5794	2.13
5548	41.19	7.05	5315	2.16	8696	89.71	22.21	5795	1.93

Table 8 – Input AGT Placement Data

Input AGT Placement Data	
Casing Depth, (ft)	6145
Casing Friction Factor	0,2
Open Hole Friction Factor	0,3
Start Depth, (ft)	6144,5
End Depth, (ft)	9000
Mud Weight, (ppg)	9,1
Weight On Bit, (klbf)	20
Scenario RPM	60
Scenario ROP, (ft/hrs)	50
Scenario Type	Drilling Ahead, Rotating

Table 9 – AGT Placement

AGT Tool Placement	Placement Rank	Color Code	By AGT (kft/lbs)	Non AGT (kft/lbs)	Torque Reduction (kft/lbs)	Reduction Factor (%)
1129 ft from bit	1		2.25	3.4	1.15	34%
1723 ft from bit	2		2.1	3.4	1.3	38%
2317 ft from bit	3		2	3.4	1.4	41%
2912 ft from bit	4		2	3.4	1.4	41%
3506 ft from bit	5		1.9	3.4	1.5	44%
4100 ft from bit	6		1.85	3.4	1.55	46%

Table 10 – Downhole Data (well B vs. A)

Parameter Drilling	Well B W/O AGT Depth (ft)		Well A W/ AGT Depth (ft)		% Difference Depth (ft)	
	6100-6600	6600-8900	6100-6600	6600-8900	6100-6600	6600-8900
BHA Component	**BHA #1** RSS + Motor	**BHA #2** RSS + Motor	**BHA #1** Motor W/ AGT	**BHA #2** RSS W/ AGT	**BHA #1**	**BHA #2**
ROP (fph)	26.35	52.33	32.80	56	20%	7%
WOB Min (lb)	10000	7000	5000	3000	50%	57%
WOB Max (lb)	12000	13000	10000	7000	17%	46%
Torque Bottom Off (ft-lb)	6000	10000	6000	7000	0%	30%
Torque Bottom On (ft-lb)	9000	14000	8000	11500	11%	18%
RPM Surf	65	135	55	100	-	-
RPM DH	150	280	280	100	-	-

Table 11 – Torque Reduction Well A

Depth (ft)	Pre Job-Planning Torque (ft-lbs)	Actual Torque (ft-lbs)	Reduction (%)
6207 - 6593	9360	8000	15%
6593 - 8696	17146	11500	33%

Table 12 – Torsional Efficiency Well B

BHA Component	Min RPM	Mean RPM	Max RPM	Torsional Efficiency (%)
Motor + RSS	65	110	290	-2%
	50	85	110	65%
	65	100	200	33%
	65	120	300	2%

Table 13 – Torsional Efficiency Well A

BHA Component	Min RPM	Mean RPM	Max RPM	Torsional Efficiency (%)
Motor + AGT	80	260	280	62%
RSS + AGT	70	100	110	80%