Implementation of Articulating Gauge Drill Bits (Tracker™) and Cerebro® Electronic Data Capture System Reduces Well Construction Time in the Republic of Belarus.

Resume

Since mid-1960s, active drilling and development of the underground deposits of the Gomel region with the use of advanced technologies in complex geological conditions of the Pripyat Trough started in Belarus [1]. Since 2016, due to step-by-step re-equipment of the drilling rig fleet for new working conditions with more "aggressive" hydraulic parameters, active introduction of PDC bits and their universal application for drilling in all fields of Belarus has started. At the same time, there is a gradual transition from the use of turbodrills and rotary bottomhole assemblies (BHA) to the use of BHA's that include a positive displacement motor (PDM) as well as rotary steerable systems. As a result, from 2016 to 2021, drilling with a BHA that includes an PDM and a PDC bit increased from 14 percent to 82 percent, as of the end of 2021 (**Table 1**).

Table 1 - Dynamics of drilling volume distribution of RUE "Production Association "Belorusneft" by years depending on the type of BHA drive

Year	Rotary Drilling	Turbine Drilling	Drilling with PDM	Drilling with RSS
2016	71%	15%	14%	0%
2017	51%	6%	43%	0%
2018	19%	0%	80%	1%
2019	13%	0%	83%	4%
2020	14,5%	0%	84,5%	1%
2021	14%	0%	82%	4%

Increasing the share of PDC bits was one of several factors that allowed to increase run length per bit and rise rates of penetration to a new level. As shown in Table 2, the average rate of penetration (ROP) has more than tripled since 2016, reaching 11.3 m/hr by the end of 2021 due to the introduction of a set of modern drilling technologies. Due to the increase of ROP it was possible to increase total volume of drilling in 2019-2021 by more than 1.5 times compared to 2016 without increasing the total number of drilling crews of the Svetlogorsk UBR RUE Production Association Belorusneft.

Table 2 - Dynamics of volumes of drilling of RUE "Production Association "Belorusneft" and average ROP

Year	Avg. ROP, m/hr	Total Meters Drilled, thsd per year
2016	3,48	107,002
2017	4	127,299
2018	4,93	137,461
2019	7,64	161,358
2020	10,3	163684
2021	11,3	164500

Introduction

According to the work of Beskopylny V. N. et al. [2] the largest assets are the Ostashkovichskoye and Rechitskoye fields. With that, more than 80 fields have been discovered, of which the vast majority consists of several deposits.

According to averaged data [3,4] at the Ostashkovichskoye and Rechitskoye fields bit sizes of 15-½ in. (393.7 mm) were commonly used to start drilling wells with a vertical conductor section from 0 to 250 meters. For the intermediate section, 11⅝-in. (295.3-mm) bits were typically used to drill from 250 to 1,100 meters TVD. For the production section, 8½-in. (215.9-mm) bits were run from 1,100 to 2,500 meters TVD; and for the liner section, 6-in. (152.4-mm) bits were run from 2,500 to 2,800 meters TVD. As shown in **Fig. 1**, the production section has been the most time-consuming drilling operations, which was about 45 percent of total drilling time. That's why this section is the main interval to increase ROP and reduce well construction time by optimizing drill bit design.

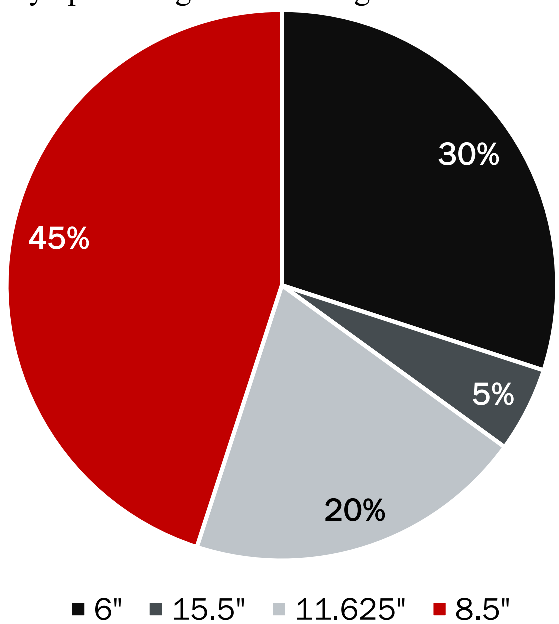


Figure 1 - Distribution of time spent drilling each section of the well

Statement of Problem

Optimized design of 215.9 mm drill bits for Production section drilling makes the greatest contribution to reduction of well construction time. The drilling interval of this section is composed of Devonian deposits, represented mainly by interbedded halite and clay with marl intercalations, as well as limestone, dolomite with rare interlayers of siltstone of various rock strength.

The main problems are ensuring the efficiency of rock destruction and control of the borehole trajectory in build-up and tangent intervals.

Several factors influence bit steerability: cutting structure, bit profile, availability of anti-vibration elements, gauge configuration, lateral aggressiveness of the bit, depth of cut (DOC) and other [5,6].

The main goal for a drill bit during the drilling process is to achieve the highest rate of penetration and footage while maintaining the planned wellbore trajectory. To achieve this goal, the drilling fluid flow rate, weight on bit, fluctuations of RPM must be within the optimal values, capable of providing maximum ROP while minimizing the level of vibration.

This paper discusses the optimization of drilling parameters to reduce vibrations, which were measured using at-bit Cerebro® sensors. **(Fig.2).**

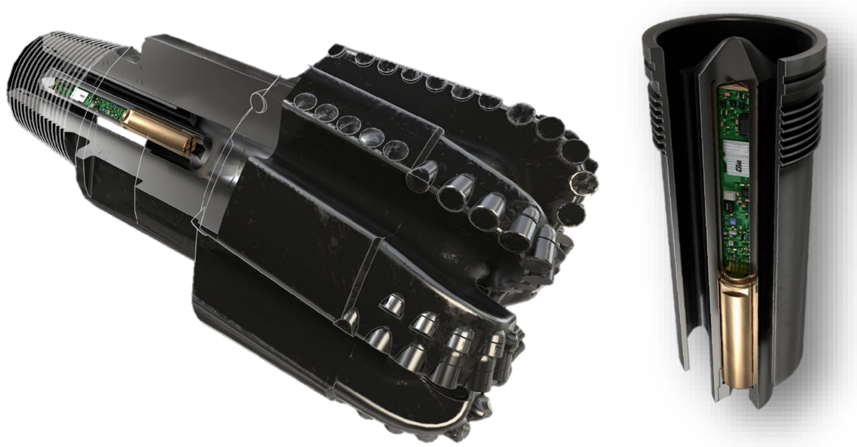


Figure 2 – Cerebro® At-bit Electronic Data Capture Module

The implemented Cerebro® In-bit Electronic Data Capture Module consists of independent 1,000Hz sensors:

- 3 axis Accelerometers
- 3 axis Magnetometers
- 3 axis Gyroscopes
- Temperature sensor

According to articles [7,8], the sensors provide continuous high frequency sampling within 150 hours, they don't have limitations for maximum flow rate of the drilling fluid or differential pressure, and even can continue recording data with rig pumps shut off. The sensors get activated at certain RPM. The module installation is available for drill bits of 149.2mm and larger sizes.

The system identifies the following dysfunctions **(Fig.3)**:

- Axial vibration
- Lateral vibration
- Torsional vibration
- Stick-n-slip vibration
- Bit Whirl

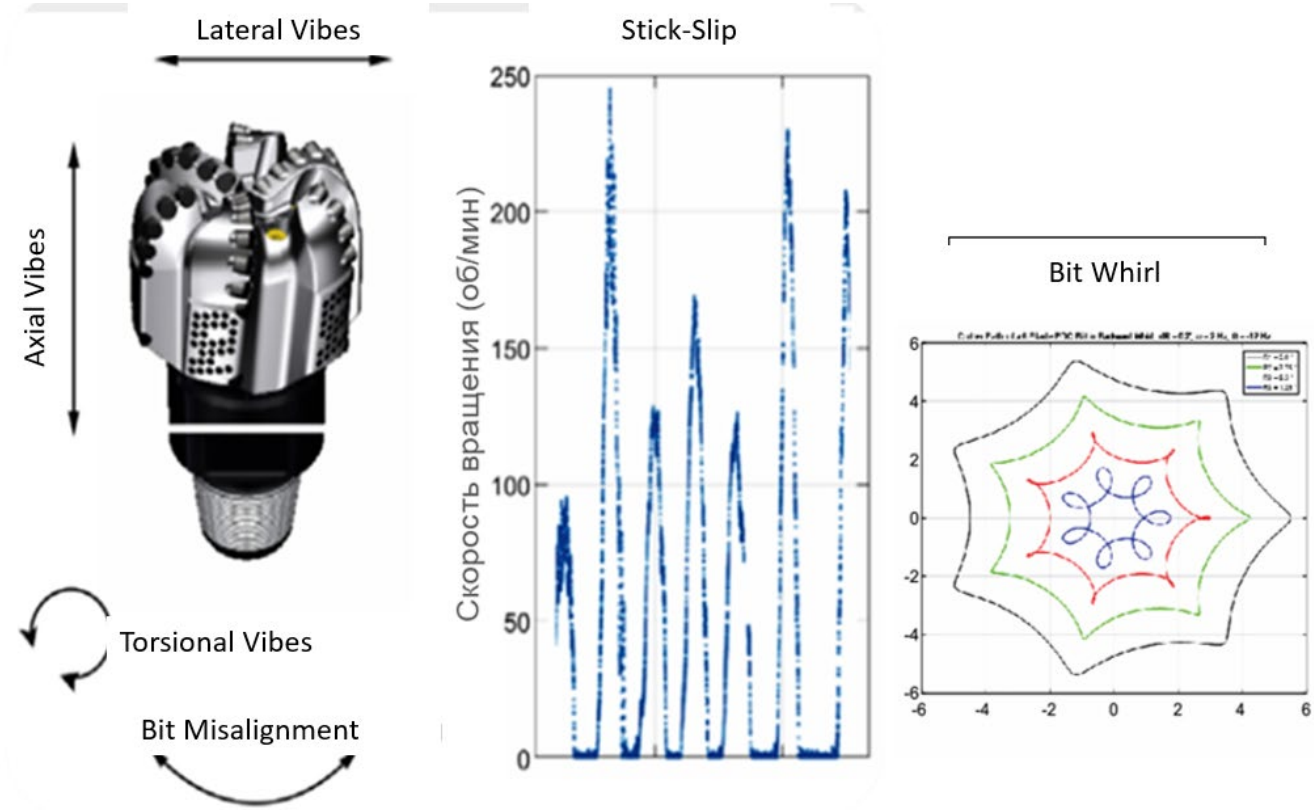


Figure 3 – Vibrations measured by the sensors

Drill Bit Evolution for Production Section Drilling

Starting from 2018, five- and six-blade matrix body PDC bits manufactured by Halliburton were used in a BHA with a PDM for production section drilling. However, later testing results showed that PDC steel body bits are more effective for drilling this interval.

The first tested GT56s steel body bit had five blades and a 19-mm cutter size. The achieved average ROP was higher than planned by 25 percent. Despite the fact that the bit was pulled out of hole (POOH) almost without wear, going through the interbedded section in the orientated drilling mode (without rotating the string from the surface), a variable reactive torque occurred with this bit, which led to a problem with tool face control. In addition, during drilling, there were problems with maintaining constant WOB due to frequent rock intercalations, which ultimately negatively affected the ROP in this mode and during the whole run. This fact proves the presence of problems related to the steerability of the BHA when drilling in interbedded layers, so the task of reducing the reactive torque on the bit became the main focus.

This topic was covered in detail in the work of Norris, J. A. et al. (1998), where it was found that it is possible to improve the steerability of an FC bit to ensure good tool face control by reducing the aggressiveness of the cutting structure of the bit. However, it is necessary to maintain a balance between improved steerability and bit aggressiveness, because too much reduction of aggressiveness can lead to a significant decrease in ROP [11, 12].

The next step in optimizing the design of an FC bit was to create a bit that would provide stable drilling in sliding mode through interbedded rocks, by reducing the torque generated by the bit itself. For this purpose, a new steel body five-blade bit design, GTD55Ks, was developed, equipped with 16-mm, 4D-shaped cutters (**Fig.4**). According to articles [3, 4] using a 4D-shaped cutter, instead of a cylinder type one, reduces the FC bit face cutter Torque generation and, thereby, improves the bit's steerability while drilling in sliding mode.

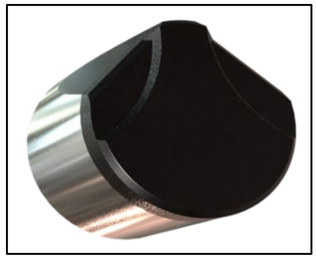


Figure 4 –Chisel^{TM} PDC cutter with a complex, geometric work surface

The use of the GTD55Ks bit with an updated shaped cutting structure significantly improved the average ROP performance per run by more than 50 percent compared to previous designs. Additionally, the newly designed bit did not have significant wear after drilling of the production section (**Fig.5**).

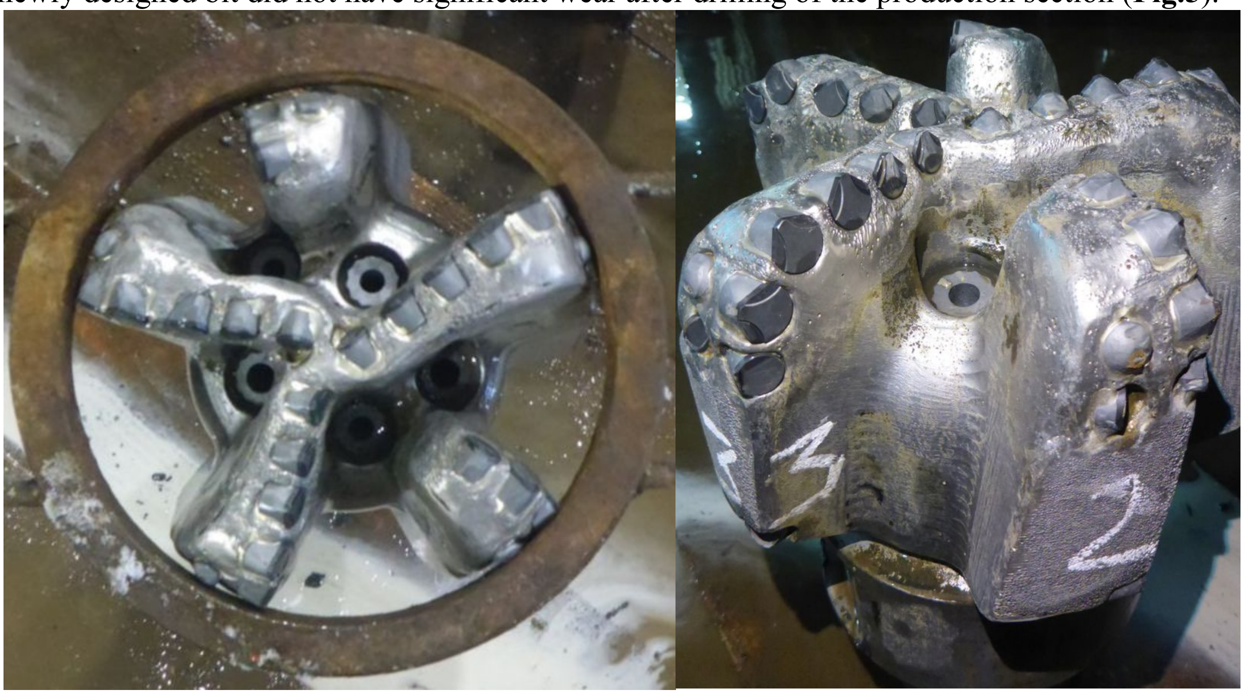


Figure 5 – Bit dull photos after drilling the production section in Well No. 410 at the Rechitskoye field

Articulating Gauge Drill Bit Loaded with Cerebro® Data Capturing System

Belorusneft is constantly working on reducing the time required for its well construction projects. That includes close cooperation with manufacturers of drilling equipment and drill bits, so that they implement the best available design, development, and manufacturing methods of these tools. Therefore, despite the positive dynamics and improvement of ROP levels with the existing HDBS FC bit designs (Table 3), it was decided to test an innovative product.

Table 3 – Average ROP's achieved with HDBS Drill Bits

Period	2018	2019	2020	2021
Avg. ROP in all sections	**4.4 m/hr**	**6.1 m/hr**	**7.5 m/hr**	**9.3 m/hr**

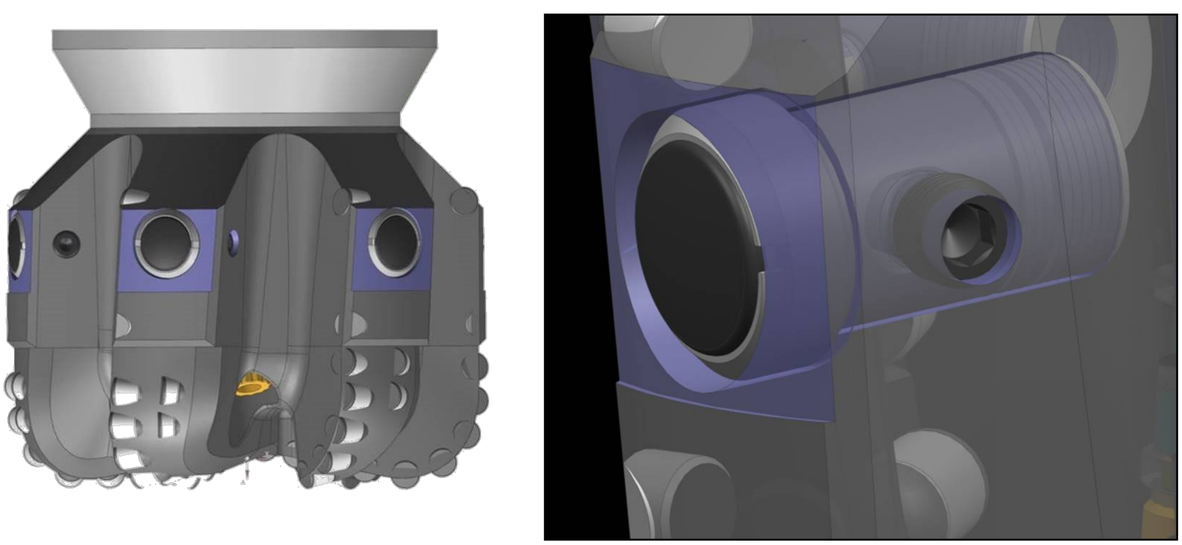
Based on the successful experience of drilling highly interbedded rocks in complex geological applications, like the Pripyat basin, a solution was proposed to use **215.9 ESD55MKO** equipped with the Articulating Gauge Tracker™ feature and 4D cutter Chopper^{TM} **(Fig.6)**. Belarus is the first country in the

Eastern hemisphere to test this technology in land drilling. The main advantages of this new bit design include:

- Improving bit stability by means of Articulating Gauge feature Tracker™
- Smoother and more predictable tool face control in directional drilling
- Utilizing Geometrix™ 4D Chopper™ main cutting structure type
- Placement a new Geometrix™ 4D Hatchet™ cutter (special characteristics of this cutter shape were discussed in more details in paper [13])
- Installing an at-bit Cerebro® data capturing module

Figure 6 –215.9 ESD55MKO with Articulating Gauge feature and Chopper™ и Hatchet™ cutting structure utilization

The Articulating Gauge Tracker™ feature **(Fig.7)** comprises moveable gage pad elements that vary lateral DOC and adjust side cutting efficiency (SCE) during drilling. The main purpose of this technical solution is to balance the high steerability provided by the shorter gauge pad design with the advantages of longer gauge pads stabilizing a bit. This approach helps reduce bit wear and improves wellbore quality (less tortuous borehole).



Fugure 7 – Articulating Gauge Tracker™

Tracker™ Drill Bit Equipped With Cerebro™ Data Capture System Field Tests Results

A production section in Well # 425 (directional) at the Rechitskoye field was selected for the first field tests. The given interval of 572 to 2,380 meters MD was drilled with **215.9 ESD55MKO** in one run. The bit successfully drilled the interval and was POOH with only slight wear of **0-0-CT-C,S-X-I-NO-TD** (**Fig.8**).

Figure 8 – Dull pictures of a test drill bit 215.9 ESD55MKO fetauring Tracker™ Articulating Gauge technology and loaded with Cerebro® after the run made at Rechitskoye well # 425

The results of drilling with the **215.9 ESD55MKO** in Well# 425 at the Rechitskoye field were used to generate a composite depth plot for subsequent analysis. This plot presents data from geophysical open-hole logs, as well as their lithological interpretation, drilling parameters, and confined rock strength, calculated on the basis of:

- Acoustic logging data
- A lithological model built from log data and available geological information

The analysis of the plot showed that the drilling interval for the production section consists of halite with layers of clay, mudstone and sandstone with confined rock strength of up to 25,000 psi. In the process of drilling with an experimental bit in a curve section in the oriented drilling mode, there have been no high values of reactive torque fluctuations recorded, even with maintaining a constant WOB over the entire interval. This made it possible to achieve high penetration rates, both when drilling in slide mode and drill string rotation, which indicates better steerability of the bit with Tracker™ feature, compared to the previously used FC bits on this project

All in all, the experimental **215.9 ESD55MKO** bit successfully drilled the interval of 572 to 2,380 meters MD for 215.9 mm Production section at Rechitskoye Well # 425 and achieved the following performance results:

- The bit Drilled the entire planned interval of 1,808 meters
- Achieved ROP = 41.4 m/hour vs planned 22.1 m/hour
- The bit was POOH in minimal dull condition
- Exceeded the planned performance by 1.9 times
- Reduced well construction time by 38.4 hour (1.6 days)

Using the **215.9 ESD55MKO** bit at the Rechitskoye field resulted in the best performance for this group of wells as of October 2021(**Fig. 9**), which helped reduce drilling time by 1.6 days, exceeding the planned performance by **1.9 times**.

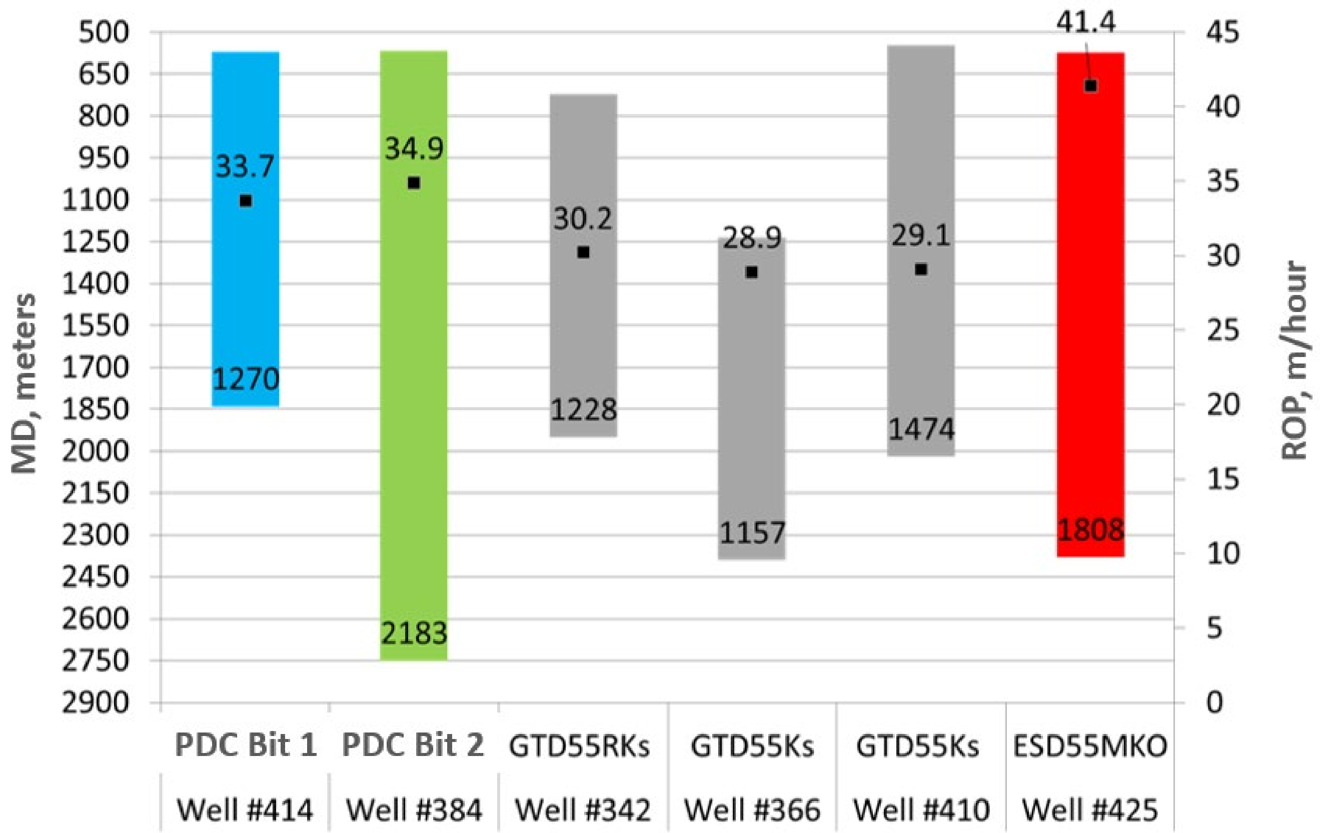


Figure 9 – Comparative dynamics of drilling a 215.9 mm section with ESD55MKO in comparison to the best FC runs at the Rechitskoye field

Cerebro® data of vibrations levels were uploaded and processed upon the run completion after the bit POOH. The results are shown in **Figure 10**.

Figure 10 – Main types of vibrations occurred during drilling the interval of 572 to 2,380 meters MD

So, 93 per cent of the whole run there were either no vibrations at all or the vibrations level did not exceed the threshold, and only 7 per cent of all the drilling time various types of Medium or High level vibrations were observed (**Fig. 11)**.

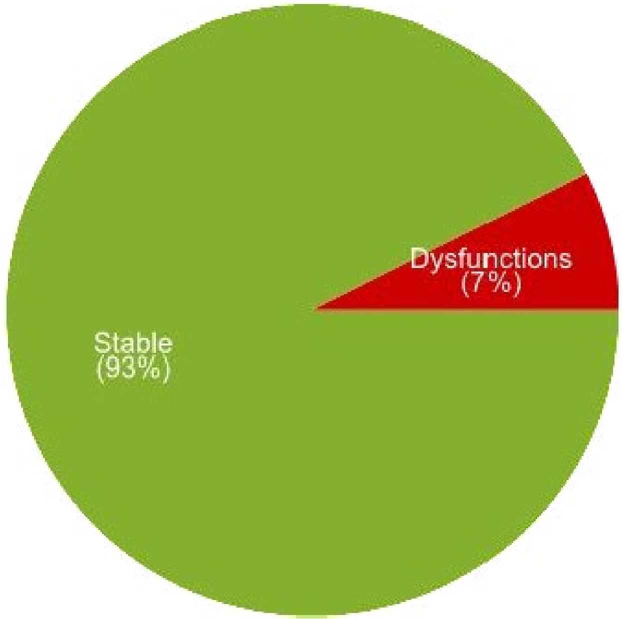


Figure 11 – 215.9 ESD55MKO Run Dysfunctions Summary

For a more detailed analysis of the causes of vibrations, a plot was built, including the drilling parameters and vibration levels, with further division of the entire run into intervals with similar drilling conditions **(Fig.12).**

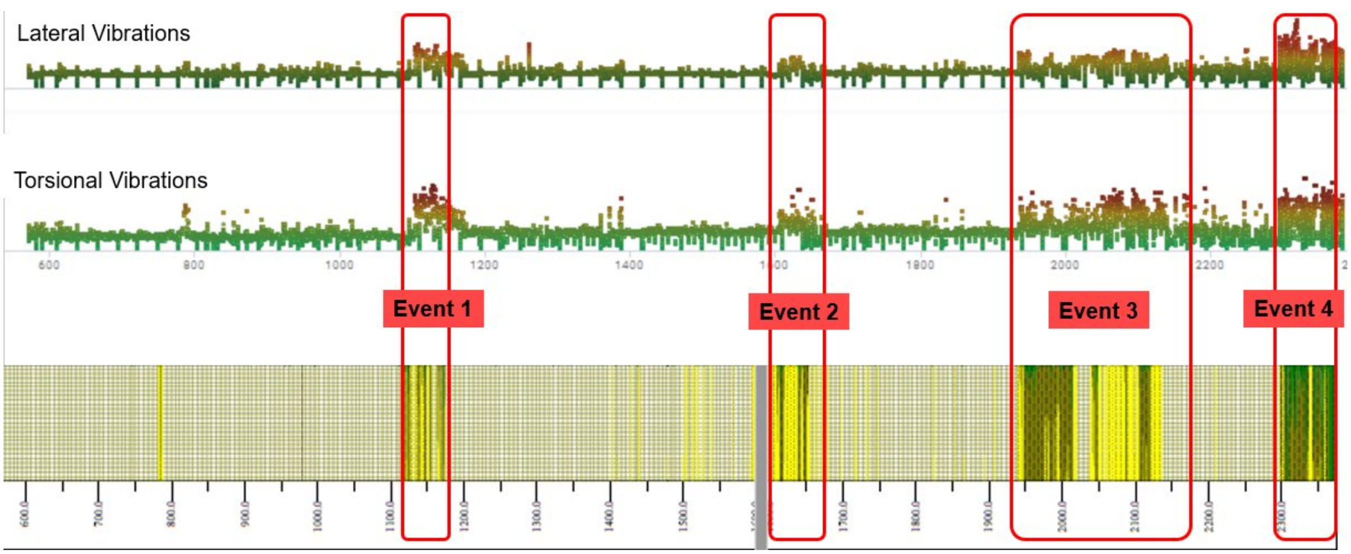


Figure 12 – General drilling data in the interval 572 to 2,380 meters at Rechitskoye Well # 425

In view of drilling of hard formations, torsional vibrations of medium and critical levels were observed during 7% of the time of the whole run. In most of the previously studied runs [7], it was found that torsional vibrations do not so much lead to bit wear, as they are destructive for downhole equipment (MDW, RSS and other downhole electronics). In the context of this run, due to insignificant bit wear, these vibrations are mainly not so much informative in the primary causes of bit wear indication, rather than of rock strength variations.

Occurrence of lateral vibrations of the bit and BHA is attributed to drilling parameters. Analysis of BHA behavior in a proprietary software MaxBHA™ also showed high probability of their occurrence at a given borehole curvature angle, at WOB 8 to 6/10 to 12 tons and 40-50 RPM (**Fig.13-14**).

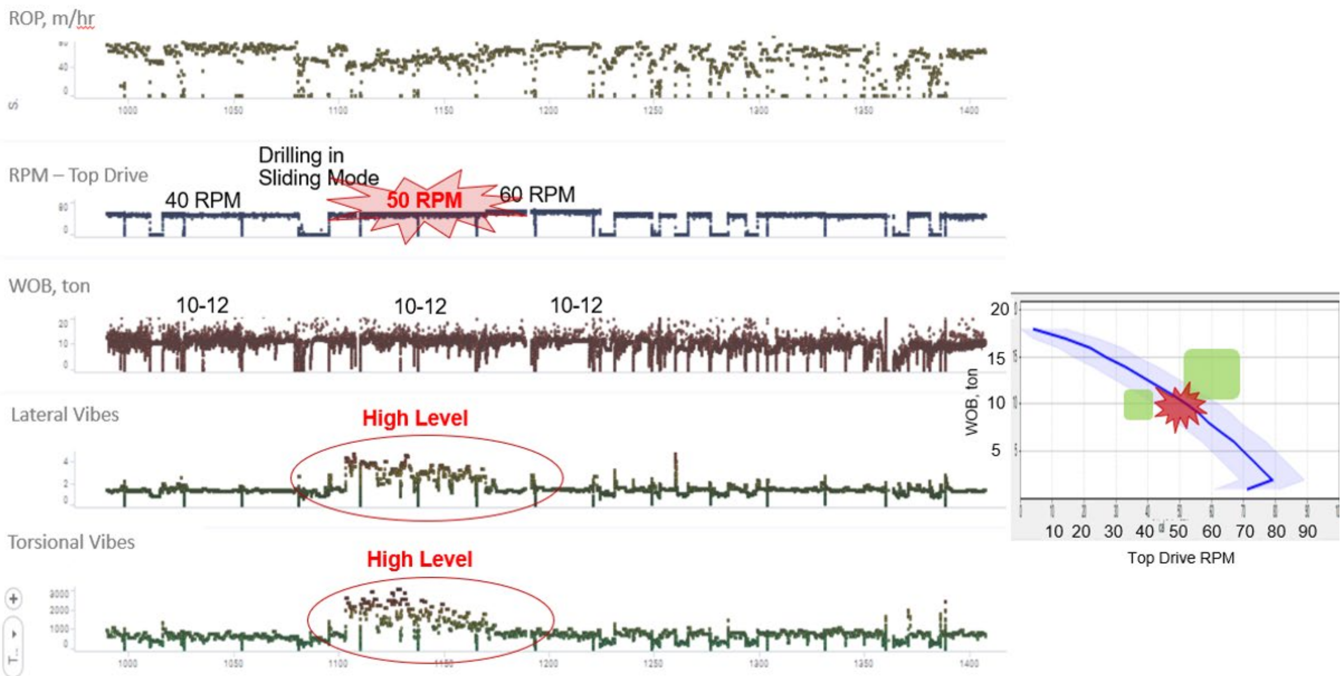


Figure 13 – Analysis of drilling the interval of 1,000 to 1,400 meters MD

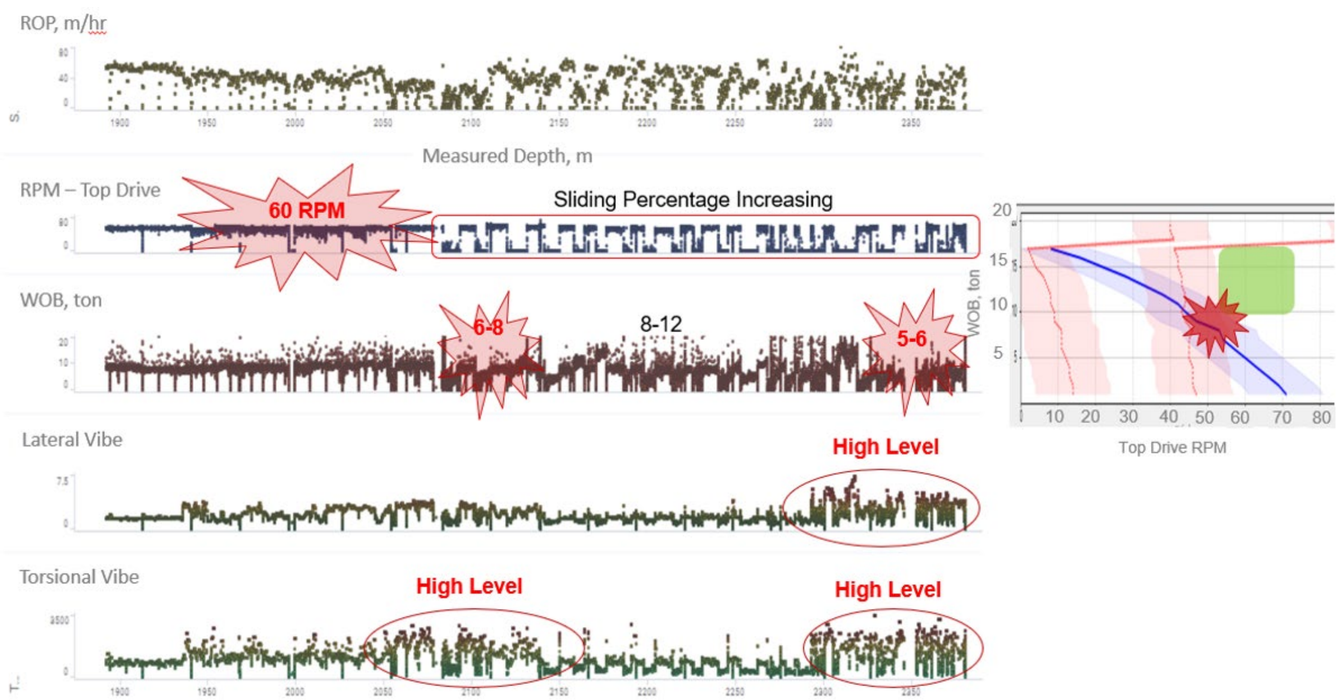


Figure 14 – Analysis of drilling the interval of 1,950 to 2,400 meters MD

Also, based on the retrieved Cerebro™ data findings, a Driller's Road Map with optimized drilling parameters for achieving maximum performance was created (**Fig.15**).
The maximum values of ROP are achieved at 50-57 top drive RPM. A decrease in ROP in this interval is observed at top drive RPM going above 60. Also, calculations in MaxBHA™ in this interval the BHA is

in the vibration critical zone at 50 RPM, meaning that in these conditions 57 top drive RPM is the most effective option. In terms of WOB, the best ROP is achieved at 12-20 kNm, which in this interval is equivalent to 8-12t. Therefore, in this interval, we recommend observing the following drilling parameters: WOB=8-12T, top drive RPM = 57 RPM. To reduce vibrations, maintain WOB at 8 t and above and RPM not less than 55 RPM. And to achieve maximum ROP, RPM should not exceed 58 RPM.

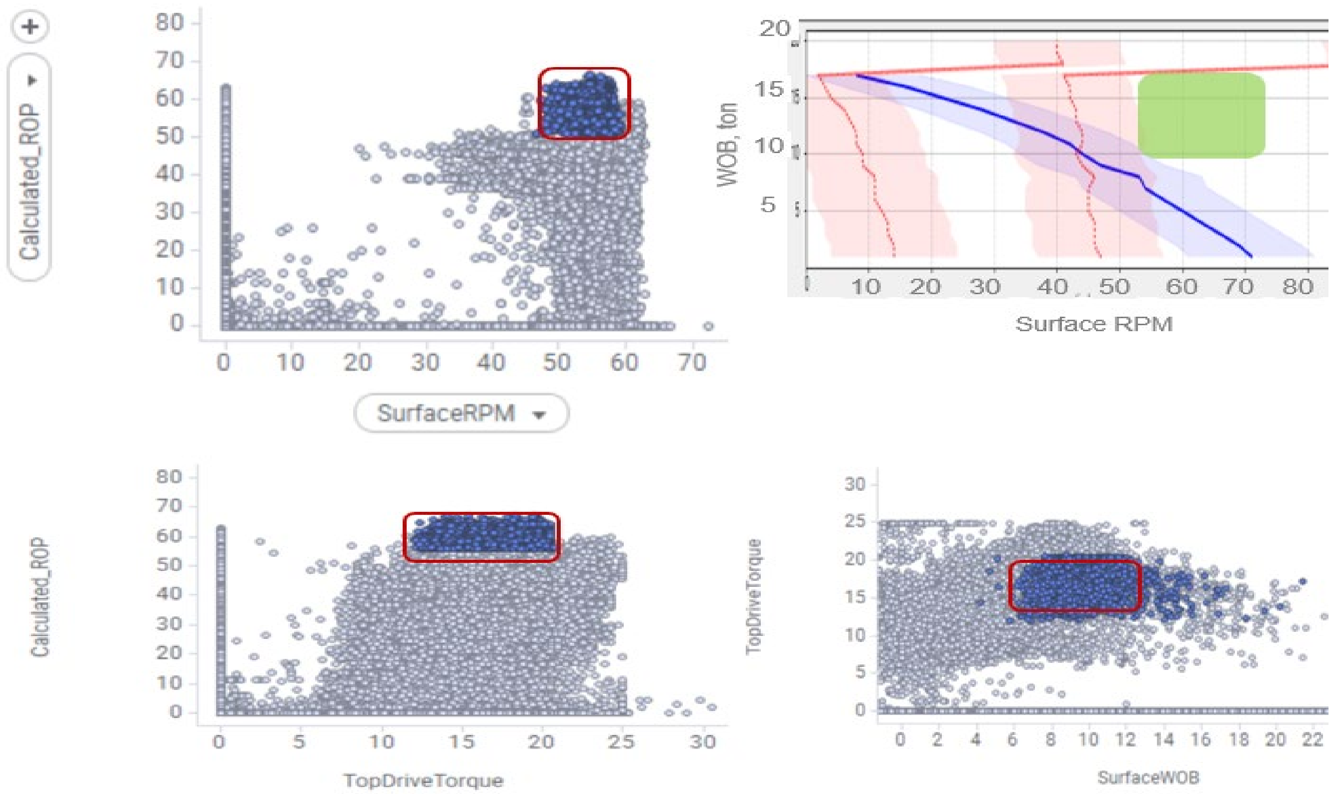


Figure 15 – Optimal drilling parameters analysis

On the basis of the work done, a road map with recommendations for drilling parameters for subsequent bit runs to achieve maximum drilling rates and reduce vibration levels in the transition zones of halite changing to harder sandstone and siltstone interlayers was developed (**Fig.16**).

Driller’s Road Map

600-1,200m		
	Halite	Sandstone, Siltstone, Shale
WOB	12-14 tons	12-14 tons
Top Drive Speed	40 or 60 RPM	60 RPM
1,200-1,700m		
	Halite	Sandstone, Siltstone
WOB	11-13 tons	11-13 tons
Top Drive Speed	60 RPM	60 RPM
1,700-2,150m		
	Halite	Sandstone, Siltstone
WOB	8-12 tons	8-12 tons (no less than 8 tons!)
Top Drive Speed	57 RPM (no more than 58)	55 RPM
2,150-2,380m		
	Halite	Sandstone, Siltstone, Shale
WOB	8-12 tons	8-12 tons (no less than 8 tons!)
Top Drive Speed	57 об/мин	55 RPM

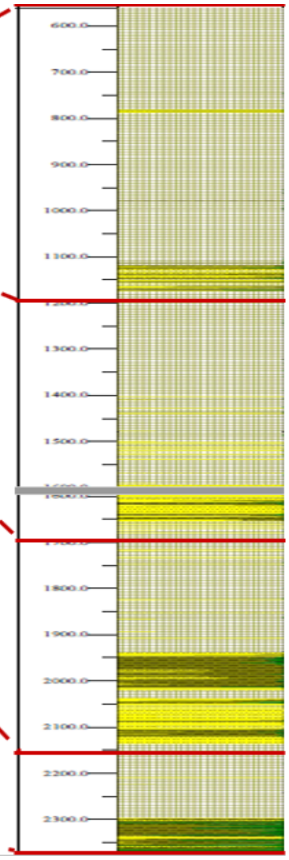


Figure 16 – Driller’s Road Map

Conclusion

The present article demonstrates a methodology for identifying and classifying vibrations that occur during drilling, which in turn reduces the overall level of dysfunctions and thereby improves drilling efficiency with the help of drilling parameters optimization. The methodology was successfully field tested at the Belorusneft fields.

Innovative technology – Articulating Gauge – allows drilling wells with complex profiles at high rates of penetration and reduces the total time and cost for well construction.

Implementation of this design feature in drill bits made it possible to achieve a new level of drilling efficiency and overall well construction process at the Rechitskoye field.