Increasing the efficiency of the wireline in the drilling rig lifting complex

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Abstract. The article deals with optimizing the work of the wireline system of the drilling rig. It reveals the characteristic failures and breakdowns of the elements of the wireline system. Based on the analysis the authors proposed to optimize the wireline system of drilling rig BU 300 EUK with 5x6 string-up by forcibly changing the involved the crown block and the wireline block sheaves to more optimal 4x5 string-up.

1. Introduction
Drilling of exploration wells involves repeated downhole operations. This specificity results from a periodic study of exposed horizons based on extractable rocks such as cores. In this rhythm the lifting complex of the drilling rig works for endurance. This action especially affects the operability of the wireline system and in particular the technical condition of the wirelines [1-5].

In turn, the wireline system itself provides a sharp reduction in the specific load on the lifting complex. The wireline operates in the optimal mode of operation rather than in the extreme mode, which provides some significant advantages: it reduces the braking and traction loads acting on such a line winding element as the draw-works drum. This fact significantly reduces the size and weight of the elements of the drilling rig lifting complex by reducing the diameter of the lines and diameters of traction sheaves and the draw-works drum winch, reducing the area of cross-sections of the lifting shaft, transmission shafts, and brake elements.

The nature of kinematic transformations in the wireline system creates a number of drawbacks: 1) the wireline undergoes a large number of bends during the movement of the wireline block during the downhole operations, 2) the wireline has constant contact with the sheaves of the wireline system, 3) the wireline gets wound and swelled from the draw-works drum at high speed, 4) there is a significant increase in the length of the traction element and the speed of the wireline winding on the draw-works drum. The wireline wraps on the draw-works drum in several layers due to the considerably longer length of the wireline, depending on the multiplicity of the wireline system tackle, and the small technological dimensions of the draw-works drum.

The imperfection of the wireline system, with all its advantages, definitely affects the durability of the wirelines, which are the most vulnerable elements in this case. The main reason for the wireline failure is metal fatigue and mechanical wear due to sheaves work and multilayer winding on the draw-works drum.
The analysis of the operation of wirelines at various drilling enterprises shows that they do not pay attention to the issue of careful operation of the lines and do not account for the indicators of wireline runtime. This usually results in the following consequences: 1) an increase in the consumption of lines, 2) incomplete development of the technical resource of lines, 3) an increase in the number of downtimes, and accidents associated with the wirelines operation.

The practice of domestic and foreign wireline operations at large volumes of well construction shows that safe, competent, and efficient operation of wireline can provide a significant economic effect, which will grow with increasing volumes of directional drilling and depth of well construction. A quantitative indicator of the efficiency of a wireline system is the durability and work performed by a wireline on raising or lowering drilling tools, drilling and casing strings. The method of determining the runtime of the wireline system and its elements, practiced in drilling companies, does not account for the parameters of the lifting complex and is usually used only to determine a comparative characteristic in such operating conditions. The use of new knowledge-intensive structures of wirelines, new elements of the lifting complex, as well as modern systems of control and monitoring raises the question of reviewing the methods of objective assessment of the wireline runtime. This makes the issues of assessing the wireline runtime relevant [6-12].

2. Materials and methods
The wireline system of the drilling rig performs tripping operations, which take a significant part of the time in the general cycle of well construction.

During exploration drilling, the number of tripping operation cycles is many times higher as compared to deep production drilling, as there is periodic excavation of the rock (core) sample to the bottom surface. It means that tripping operation, as a technological operation, is the most important target for the search of methods to optimize the well drilling process.

There are two ways to optimize wirelines system of the drilling rig:
1) changing the design of the lifting complex of drilling rigs: preparation and implementation of new constructions of the lifting complex,
2) elaborating on the methods of parameters calculation: search for the regime and design parameters of the optimal value for the wireline systems of drilling rigs.

Optimizing the parameters of the downhole lifting complex has its own peculiarities: 1) a huge range of measures and actions determining the technological process of well installation; 2) operation of the equipment included in the lifting complex, in conjunction with each other; 3) a significant number of designs and a variety of influencing factors.

These features determine the number of variables to be determined. Optimization of the downhole lifting complex of drilling rig goes in two directions:
1) parameter optimization;
2) structure optimization.

The variation in the parameters of the downhole lifting equipment of the drilling rig is limited by the listed requirements:
1) maintenance of technical equipment performance at the level of the value specified in the requirements of the technological process;
2) possibilities of technical realization for object of execution required by the customer;
3) application of safe methods of plant maintenance and operation.

Such conditions result from imposing restrictions on the following parameters:
1) maximum lifting speed;
2) maximum speed of tool descent;
3) maximum speed of line winding on draw-works drum;
4) maximum allowable hook force for the selected installation;
5) maximum drive power;
6) maximum weight of drilling equipment;
7) complex universal capability.
The technology for optimizing the technological process of the downhole lifting complex provides further improvement of the units, increases their efficiency.

Application of the practical results obtained from optimizing the parameters of the downhole lifting complex will ensure the improvement of technical and economic indicators of the drilling exploration well.

A steel line is a non-repairable product whose durability and lifetime depends on the following parameters: 1) wireline quality; 2) structural parameters of lifting force elements, load and features of well drilling, and correct exploitation.

The main criterion for the rejects of wirelines during operation is the number of broken wires at the laying step determined by the visual inspection of the most worn sections of the wireline.

During the tripping operations in the wireline system, the line has to pass through tackle sheaves many times, which eventually causes fatigue damage and wear of outer wires.

When the line passes through the sheave, the wires suffer double bend and wear out through the contact of the wireline with the sheaves. A significant part of the wireline wraps on the draw-works drum in several layers. The wireline undergoes multiple loads, whose number is equal to the number of drill string stands, and the nature of the load is unsteady.

The number of wireline loads, the number of bends on the blocks, the multi-layer winding damage factor, and other wear factors depend on many parameters of the lifting system and can be optimized.

Such parameters include the multiplicity of the tackle and the diameter of the sheaves of the wireline system, the derrick height and the stand length, the diameter, and length of the draw-works drum.

The maximum number of double bends in a wireline section depends on the following parameters: derrick height; tackle multiplicity; length of a standard drill pipe stand. The section of the double bend undergoes wear on the sheaves, i.e. its durability determines the durability of the entire wireline in string-up.

Possible ways to increase the durability of the wirelines are as follows:

1) applying wireline bypasses or slipping and cutting in the wireline system, so wirelines supplied to drilling rigs are longer than required for the rigging of the wireline system, the wireline system has a fixed wireline section fastening device for performing the bypasses;
2) straightening and pre-drawing of wirelines during manufacture, which significantly reduces the laying stress and residual torque in the line, pre-drawing of wirelines increases their durability;
3) increasing manufacturing accuracy and development of new designs of wirelines;
4) developing and introducing of new wireline lubricants;
5) introducing devices that ensure the lubrication of wirelines during operation;
6) specifying the requirements for traction sheaves and screw threading on the draw-works drums;
7) using coated traction sheaves;
8) improving the design of the draw-works drums and screw threading to improve the conditions of multi-layer wireline winding;
9) improving the kinematic schemes of the wireline system, introduction of the system with two running ends, etc;
10) reducing vibrations in the running section of wireline with the help of wireline stabilizers and dampers;
11) ensuring the necessary tension of the running section when winding the line on the draw-work drum;
12) reducing dynamic loads by applying control systems to the drive and brake of draw-works.

The sequential interaction of the wireline with the sheaves that it bends in the wireline system results in a discrete, i.e. multiple of an integer, distribution of the bends along the length in the string-up, and an increase in the number of bends from one section to the next occurs gradually, increasing by one. The analysis of the obtained expressions determining the number of double bending of the wirelines on the sheaves shows that there are ratios of the derrick height, the height of the lift and the...
multiplicity of the string-up, at which the total number of bends of the wireline can be minimized for all runs. Compliance with these ratios will increase wireline durability.

The choice of the optimal ratio of derrick height, string-up multiplicity, and elevator lifting height can increase the durability of wirelines by 10-15%.

The wireline durability at work on sheaves depends on the law of the fatigue curve. When determining the durability or the number of wireline bends on the blocks, it is necessary to bring the wireline load to a constant equivalent load level.

3. Results

When lifting long drill strings, the total number of tripping operations will decrease with increasing stand length. The number of lifting system loads will also decrease since the number of stands with a longer length will reduces in the string. Therefore, the assessment of the wireline durability according to the above criterion requires considering the total number of wireline bends on the sheaves.

When lifting the string, the running (movable) end of the wireline carries the highest tension, the fixed end of the wireline carries the lowest tension.

The tension of the running end of wireline is determined by the formula

$$P_{RN} = \left(\frac{Q_h + P_{eq}}{\beta^{m-1}}\right) \cdot \beta^m \cdot (\beta - 1),$$

where $Q_h$ is the maximum load on the hook, N;

$$Q_h = q \cdot L_w,$$

where $q$ is the weight of the 1st running meter of the drilling tool, $q=300$ N/m (according to GOST 16293-89 "Complete drilling rigs for production and deep exploration drilling. The main parameters"); $P_{eq}$ is the weight of constantly lifting equipment (hook of drilling, wireline block), $P_{eq}=5 t = 5000$ kg = 50 kN; $\beta$ is coefficient of sheave resistance, $\beta=1.03$; $m$ is the multiplicity of tackle (the number of working strings of the wireline system), $m = 2 	imes 6 = 12$ (for equipment 5x6).

$$Q_{\beta} = 300 \cdot 2000 = 600000 \text{ H} = 600 \text{ kN}.$$

The tension of the fixed end of the wireline is determined by the following formula

$$P_{WB} = \left(\frac{Q_h + P_{eq}}{\beta^{m-1}}\right) \cdot \beta - 1$$

$$P_{FE} = 1.03^{10} \cdot (1.03 - 1) \cdot \frac{(600000+50000)}{(1.03^{10} - 1)} = 78467 \text{ N}.$$

Determining the tension of working strings:

$$S_1 = P_{RN} \cdot \frac{\beta}{\beta^m - 1} = 78467 \cdot \frac{1}{1.03} = 76181 \text{ N}$$

$$S_n = S_{n-1} \cdot \frac{1}{\beta}.$$

The tensions of the other strings are similarly calculated: $S_2 = 73962$ N, $S_3 = 71807$ N, $S_4 = 69716$ N, $S_5 = 67685$ N, $S_6 = 65714$ N, $S_7 = 63800$ N, $S_8 = 61942$ N, $S_9 = 60137$ N, $S_{10} = 58386$ N.

$$P_{FE} = \frac{(600000+50000)}{(1.03 - 1)} \cdot (1.03^{10} - 1) = 56682 \text{ N}.$$

Determining the efficiency of the wireline system

$$\eta_{w_s} = \frac{\beta^{m-1}}{m \cdot \beta^m (\beta - 1)} = \frac{1.03^{10} - 1}{1.03^{10} - 1} = 0.953.$$

Number of stands in the string:

$$q_l = \frac{L_w}{(CTPPc_4) \cdot C_4},$$

where $L_w$ is the length of the well; $L_o$ is the length of the drill string stand.

$$q_l = 24000/24 = 83; q_l = 27000/27 = 74.$$

The total number of bends of the most loaded wireline section of all stands:

$$n_l = 2 \times 6 \cdot q_l \cdot B = \eta_{max},$$

where 2 considers the doubling of the number of line bends due to the double track of the wireline block.

$$n_l = 24 \times 83 \times 5.6 = 929; n_l = 2 \times 74 \times 6.3 = 932.4.$$
The number of bends made by the wireline for both options differs by no more than 3%.
Changes in stand height by 0.5...1 m lead to changes in the optimal stand length. Determining the optimal length of the stand should consider the accurate movement of the wireline block during the tripping operation (Figures 1-4).

Figure 1. Force distribution in the working sections of the wireline depending on the string-up

Figure 2. Dependence of the number of wireline bends as a function of the stand length

Figure 3. Dependence of the total number of wireline bends on the well length
Figure 4. Dependence of force in the string-up sections of the wireline system

4. Conclusion

The choice of the optimal ratio of derrick height, multiplicity of tackle, and elevator lifting height increases the durability of the wirelines by 15 ... 20 %. Determining the optimum bypass length when working on wireline and using the spare length of the line from the drum, as well as timely bypass based on a full assessment of wireline runtime increases the technical life of the lines and their durability. Estimation of the runtime of wirelines with the account of the lifting complex operation parameters, the spreading of wear of the wireline over its entire length in the wireline string-up with regard to its multiplicity of tackle and the real load during all cycles of tripping operations, which contributes to the efficiency of the wireline operation, identification and elimination of factors that have a significant impact on the wear index to optimize the operation of the wear with the use of the bypass method.

References
[1] Hua Jian, Zhou Sizhu and Hu Lei 2015 Structural dynamics modification for derrick of deep well drilling rig based on experimental modal test and frequency sensitivity analysis Advances in mechanical engineering 7(9) 1687814015605746
[2] Luo Ju, Li Liang-Gang and Yi Wei 2014 Working Performance Analysis and Optimization Design of Rotary Drilling Rig under on Hard Formation Conditions Int. (China) Geological Engineering Drilling Technology Conf. 73 23-28
[3] Shaidullina R M, Amirov A F, Mukhametshin V Sh and Tyncherov K T 2017 Designing Economic Socialization System in the Educational Process of Technological University European J. of Contemporary Education 6(1) 149–158. DOI: 10.13187/ejced.2017.1.149
[4] Rogachev M K and Mukhametshin V V 2018 Control and regulation of the hydrochloric acid treatment of the bottomhole zone based on field-geological data J. of Mining Institute 231 275-280. DOI: 10.25515/PMI.2018.3.275.
[5] Zeigman Yu V, Mukhametshin V Sh, Khafizov A R and Kharina S B 2016 Prospects of Application of Multi-Functional Well Killing Fluids in Carbonate Reservoirs SOCAR Proceedings 3 33–39. DOI: 10.5510/OGP20160300286
[6] Sun Youhong, Shi Yuanling and Wang Qingyan 2018 Study on speed characteristics of hydraulic top drive under fluctuating load J. of petroleum science and engineering 167 277-286
[7] Almukhametova E M, Shamsudinova G F, Sadvakasov A A, Tyncherov K T, Petrova L V and Stepanova R R 2018 Modeling development of Fyodorovsky deposit IOP Conf. Ser.: Mater. Sci. Eng. 327(4) 042100. DOI: 10.1088/1757-899X/327/4/042100.
[8] Rogachev M K, Mukhametshin V V and Kuleshova L S 2019 Improving the efficiency of using resource base of liquid hydrocarbons in Jurassic deposits of Western Siberia J. of Mining Institute 240 711-715. DOI: 10.31897/PMI.2019.6.711
[9] Tyncherov K T, Mukhametshin V Sh, Paderin M G, Selivanova M V, Shokurov I V and Almukhametova E M 2018 Thermoacoustic inductor for heavy oil extraction *IOP Conf. Ser.: Mater. Sci. Eng.* 327(4) 042111. DOI:10.1088/1757-899X/327/4/042111

[10] Yakupov R F, Mukhametshin V Sh and Tyncherov K T 2018 Filtration model of oil coning in a bottom water-drive reservoir *Periodico Tche Quimica* 15(30) 725-733

[11] Zainagalina L Z, Suleimanov R I, Gabdrakhimov M S and Khabibullin M Ya 2018 Determining oscillating system dynamic parameters of a near-bit junk pulper *Advances in Engineering Research* 157 642-645

[12] Khabibullin M Ya and Suleimanov R I 2019 Automatic packer reliability prediction under pulsed transient flooding of hydrocarbon reservoirs *IOP Conf. Ser.: Mater. Sci. Eng.* 560(1) 012024. DOI: 10.1088/1757-899X/560/1/012024.