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Study of the evolution of equipment used for drilling oil and gas wells

Studium rozwoju sprzętu używanego do wiercenia otworów naftowych i gazowych

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ABSTRACT: The prospects for further improvement of the oil and gas industry are mainly related to the development and commissioning of high-yield fields. In this regard, it is of great importance to produce more economical and durable oil and gas field equipment by machine-building enterprises, increasing its reliability and competitiveness, as well as further improving manufacturing processes. Such development of technical systems follows the law of progressive evolution, reflecting changes aimed at eliminating shortcomings identified during operation. Consequently, the evolution of technology in a broad sense involves changes in design, manufacturing technology, their direction, and patterns. This article is devoted to the study of the evolution of technical systems – specifically, drilling rigs – during the period of their slow development and the approach of the efficiency criterion to the limiting value. The stages of modernization and reorganization in drilling equipment production, including the adoption of a top drive system, are discussed. Attention is also given to the production of mobile drilling rigs. The article demonstrates that the most effective way is to provide service support in various operating conditions through timely diagnosis and application of appropriate types of equipment maintenance and repair. It has been determined that the evolution of equipment used for drilling oil and gas wells has enabled the identification of key factors affecting their efficiency. Several technical areas have been identified, the development and use of which will enable further advancements in the evolution of drilling rigs.

Key words: drilling rigs, evolution, quality, modernization, service, diagnostics, maintenance, repair, mobile units.

STRESZCZENIE: Perspektywy rozwoju przemysłu naftowo-gazowego wiążą się głównie z rozwojem i uruchomieniem wysokowydajnych złóż. W związku z tym bardzo ważne jest aby przedsiębiorstwa zajmujące się budową urządzeń produkowały bardziej ekonomiczne i trwałe wyposażenie do eksploatacji złóż ropy naftowej i gazu ziemnego, zwiększając jego niezawodność i konkurencyjność, a także ulepszając procesy produkcyjne. Taki rozwój systemów technicznych odbywa się zgodnie z prawem stopniowej ewolucji, odzwierciedlając zmiany mające na celu wyeliminowanie niedociągnięć zidentyfikowanych podczas użytkowania. W związku z tym ewolucja technologii w szerokim znaczeniu obejmuje zmiany w projektowaniu, technologii produkcji, ich kierunku i wzorcach. Niniejszy artykuł poświęcony jest badaniu ewolucji systemów technicznych, w szczególności platform wiertniczych, w okresie ich powolnego rozwoju oraz w miarę jak kryterium efektywności zbliża się do wartości granicznej. Omówiono etapy modernizacji i reorganizacji produkcji urządzeń wiertniczych, w tym wprowadzenie napędu górnego. Zwrócono również uwagę na produkcję mobilnych urządzeń wiertniczych. W artykule wykazano, że najskuteczniejszym sposobem jest zapewnienie wsparcia serwisowego w różnych warunkach pracy poprzez terminową diagnozę i zastosowanie odpowiednich rodzajów konserwacji i napraw sprzętu. Ustalono, że ewolucja sprzętu wykorzystywanego do wiercenia otworów naftowych i gazowych umożliwiła identyfikację kluczowych czynników wpływających na ich wydajność. Zidentyfikowano kilka obszarów technicznych, których rozwój i wykorzystanie umożliwi dalszy postęp w ewolucji urządzeń wiertniczych.

Słowa kluczowe: urządzenia wiertnicze, ewolucja, jakość, modernizacja, serwis, diagnostyka, konserwacja, naprawa, jednostki mobilne.

Introduction

The operating conditions of equipment used in well drilling and oil and gas production are known to be challenging, often characterized by the impact of unfavorable environmental conditions, including high levels of stress and variable operating loads. As a result, there is often insufficient operational reliability, leading to a significant amount of repair and restoration work, including the replacement of systems and units under operating conditions. This, in turn, requires an increase in the technical level and reliability of the oil and gas field equipment used, improving its technical, economic and operational indicators.

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Studies (Salamatov, 1996; Litvin and Gersman, 2010) indicate that the development of technical systems (TS) follows the law of progressive evolution, reflecting changes aimed at eliminating shortcomings identified during operation. Separate stages of such research in relation to oil and gas field equipment (OGFE) are discussed in works of Babaev et al. (2018, 2020), which identify the characteristic features of the dynamics of development of specific TCs, reflecting not only a one-time cycle of formation of their reliability, but also the dialectical development and improvement of methods, as well as the nature of developments to increase the quality and reliability of equipment.

Thus, the further development and improvement of any TS is based on the entire history of its design and technological evolution. The study of the evolution of the TS makes it possible to identify the main stable factors influencing its development, as well as the technical and technological capabilities of the transition to the next stage.

Very often, TS – parts, assemblies, and units, which are connected with some commonality (first of all, which have the same functions with a TS) – undergo similar development stages in their evolution. These cases are referred to as "parallel lines of evolution" (Litvin and Gersman, 2010), because knowing the current stage of development of one system, typically the more advanced, it becomes possible to reliably predict the evolution of the other system.

Thus, the evolution of technology in a broad sense is the idea of changes in designs, manufacturing technology, their direction and patterns. In this case, a certain state of any class of TS, including the object of this research, drilling rigs, is considered as the result of long-term changes in its previous state; transition from existing and practically used TS to new models that differ from previous designs. These transitions, generally involve improvements in certain efficiency criteria or quality indicators of the TS and are usually progressive in nature.

Goal of the work

Given the above context, the study of the evolution of drilling rigs is a considerable and complex endeavor. Drilling rigs comprise numerous functionally connected and interacting main and auxiliary systems, units, and mechanisms, which together form a unified technological complex that carries out the transfer of oil and gas wells. In addition, drilling rigs are equipped with various auxiliary equipment and mechanisms designed to perform additional functions not directly related to the drilling process. These include installation and transport bases or assembly-dismantling bases, lifting equipment for mechanized tasks, etc. Mobile drilling rigs, mounted on a wheeled or tracked transport base, are also increasingly used for drilling exploratory wells.

It is interesting to analyze the initial state of the fleet of drilling rigs produced in the late 1980s and 1990s and beyond until the post-crisis recovery in demand for rigs due to an increased drilling volumes. During this period, the main manufacturers of drilling rigs (DR) for deep drilling of oil and gas wells were the Volgograd Drilling Equipment Plant (VDEP) and Uralmash – Drilling Equipment CJSC. These installations primarily relied on traditional lifting mechanisms with traveling systems, drawworks, rotors, and swivels. For a long time, the evolution of such installations involving adding only auxiliary technical devices, primarily to reduce time spent on hoisting operations. Examples of such devices include pneumatic rotor wedges (PRW), automatic drill wrenches (ADW), and others.

Study of the evolution of drilling rigs

Studying the evolution of drilling rigs is a challenging task due to the significant economic changes that occurred in the 1990s.

As noted in work of Kershenbaum (2015), a significant part of the DR fleet was produced in the late 1970s and 1980s. However, in general, the competitiveness of DR remained high. Negative factors included long delivery times, an often insufficient level of automation and computerization, ineffective interactions with customers, and poor service support.

The wear and tear of the drilling rig fleet in the post-crisis period is also highlighted by the data presented by (Vladimirov and Kershenbaum, 2009), showing that of the total number of rigs with a lifting capacity of 160 tons, a significant part had been in service for more than 10 years, while the rest of them reached the end of service life, requiring replacement or modernization.

At the end of 2005, the German company KSA Deutag carried out an analysis of the condition of the Russian rig fleet. It confirmed that approximately 70% of the equipment requires modernization and, in many cases, replacement within the next 5–8 years. The work notes several reasons for the rush to renew the DR fleet in 2005–2007. First, rising oil prices and expansion into new regions increased the demand for well drilling. Second, there had been a 15–20 year period during which the fleet had not been renewed. In response, a modernization program was adopted, aiming to improve the quality and environmental characteristics of drilled wells, reduce accident rates and drilling time.

Taking into account the current situation, based on the equipment modernization program, a phased restoration and import substitution of plant equipment was carried out. This was further supported by the construction of a plant for the production of Bentek drilling rigs in Tyumen.

In general, the modernization program and the introduction of after-sales service have helped reduce well construction time and accident rates, significantly improve the quality and economic performance of production, and enhance drilling efficiency. As mentioned above, traditional rigs with a traveling system, drawworks, rotor, and a swivel were long used for oil and gas drilling. The main disadvantage of the TS data, which contributed to higher production costs (or the cost per the volume of wells drilled), was the significant time (up to 30–35%) spent on lowering and lifting operations.

As noted by Atchison and Sarpangal (2022), operating traditional drilling rigs is associated with dangerous situations, often resulting in accidents and injuries to operating personnel. This is particularly true during such repetitive operations like lowering casing strings and lowering and raising drill pipes, where the drilling crew is often located in the most dangerous area near the rotor wedges (Habibov and Abasova, 2022).

To enhance work safety on drilling rigs, an unconventional drilling rig (without a traveling system or drawworks), based on hydraulic drives (HH series), was developed in Italy with the participation of ENI and Agip companies (1995).

In the early 2000s, Drilltec (a subsidiary of the Italian corporation Trevin Group) launched serial production of automated drilling rigs based on hydraulic drives, with a nominal static load capacity of 750–6000 kN, for drilling wells up to 5000 m deep, including directional wells. These rigs required fewer personnel, with most operations conducted automatically or by remote control, enhancing safety at the drilling site and reducing drilling crew size. Subsequently, based on the positive experience with the HH series drilling rigs, Drilltec developed a new series of AHEAD (Advanced Hydraulic Electrical Automated Driller) – a standard range of hydraulic drilling rigs from 780 to 1542 kW (from HH102 to HH350), with lifting capacities from 100 to 317 tons and weights from 43 to 120 tons.

Significant productivity and safety improvements in hoisting operations were achieved through the use of a top drive system, which includes in particular a pipe manipulator that facilitates the work of drillers. In addition, this system combines the functions of a traveling system, rotor, swivel, and offers several additional advantages (Andriyanov et al., 2018).

In 2007–2008, CJSC Uralmash – Drilling Equipment (UrDE) joined the InteGra group of companies, followed by a major reorganization that led to the creation of InteGra – MashService LLC service company.

The involvement of other service companies, particularly the Siberian Service Company (SSC) and KSA Deutag, was instrumental in providing service support, equipment and maintenance, and repair work using modern technologies.

To significantly enhance the technical capabilities of domestic drilling rigs, UrDE created the "Ekaterina" drilling rig (DR 3000 EUK) in a modular design, with a lifting capacity of 270 tons and a drilling depth of 4500 m. The installation's winch, with a DC electric drive, omitted traditional components such as chain transmissions, tire-pneumatic clutches, or electromagnetic, hydrodynamic, and band brakes. In addition, the installation was equipped with a top drive system, a modular cementing complex block, and triplex mud pumps (Babaev et al., 2018).

Furthermore, the "Ekaterina" rig was designed for cluster drilling of wells up to a depth of 4,200 m. The main goal of comprehensive modernization in this case was to increase the lifting capacity and drilling depth of the rig, equipping it with more modern and technologically advanced equipment allowing to increase the penetration rate.

In many regions, wells were drilled in areas with no access roads, so mobile drilling rigs (MDR) were required. The demand for rigs is also linked to the technology of drilling complex and horizontal sections of wells and the need to reduce the time required to move the rig from one point to another. In the USA, for example, mobile units accounted for up to 35% of the rig fleet during this period (Vladimirov and Kershenbaum, 2009).

The Russian "KUNGUR" group of companies, which manufactures mobile drilling complexes with lifting capacities of 125, 180 and 250 tons, plays a significant role in the production of drilling rigs. These installations, according to experts, meet modern requirements for MDRs used for deep drilling of production and exploration wells, their overhaul, and restoration.

It is known that the balance of the time associated with the process of drilling for oil and gas (as well as during capital repairs of wells) consists of the time spent on performing a set of specific works. The most important among these is the time spent directly on drilling the well (driving on the bit), during which it is especially important to ensure the trouble-free operation of the installation equipment. In particular, the high-pressure pumps used must ensure the supply of the required amount of flushing fluid into the well, effective cleaning of the bottom hole from drill cuttings, and, consequently, the normal operation of the bits.

During drilling operations, mud pumps of the U8-6M (UNB-600) type, produced by the Uralmash plant, are primarily used (Babaev et al., 2018). These pumps, which are double-cylinder, double-acting piston pumps with a power of 600 kW and a maximum average pressure of 25 MPa, are designed for drilling wells up to 5000 m deep. Foreign companies (in particular National Oilwell Varco) produce mainly three-piston single-acting pumps (Vladimirov and Kershenbaum, 2009).

The failure-free operation level of the hydraulic part of U8-6M type mud pumps, according to Babaev et al. (2017), shows an average time to failure $T = 51.46$ hours, with a standard deviation $\sigma = 50.92$ hours and a coefficient of variation $V = 0.99$.

Since the required uptime of mud pumps should be sufficiently longer than the time spent on penetration, it is of interest to analyze the corresponding comparative data with a study of their quality and uniformity.

For this comparative analysis, the results of comparative tests of roller bits with milled gears produced by "Volgaburmash" OJSC and foreign companies: Hughes, Reed, Smith, Security DBS, Tsukamoto were used. The tests were carried out under identical conditions of drilling wells up a depth of 4,500 m at "Orenburgneft" JSC, under the same operating modes and drill string layouts. A total of 22 bits were tested: 11 produced by "Volgaburmash" OJSC (sample I) and 11 by foreign companies (sample II). Drilling time per bit for bits from "Volgaburmash" OJS ranged from 24.5 to 67.0 hours, with an average of 45.2 hours. For bits from foreign companies, drilling time ranged from 23.2 to 76.8 hours, with an average of 53.2 hours.

The general variation series of two samples: $n = 11$ and $m = 11$, along with its ranking, is shown in the table, where each drilling time value is assigned a rank from 1 to $n + m$ (Table 1).

The hypothesis that the two specified samples belonged to a single population was tested using the nonparametric Wilcoxon, Mann, and Whitney rank test, which is particularly effective when the sample size is $n + m \geq 20$ (Babaev et al., 2015). Based on the calculations, the null hypothesis that the two considered samples belong to a single general population is not rejected. When combining samples, the average drilling time per bit, based on the totality of samples, was: $\bar{\tau}_d = 49.2$ hours.

Table 1. General variation series of samples and their ranking
Tabela 1. Ogólny szereg wariacyjny próbek i ich ranking

Rank	Drilling time [hours]	Sample number	Rank	Drilling time [hours]	Sample number
1	23.2	II	12	51.0	II
2	23.7	I	13	52.7	I
3	24.5	I	14	53.4	I
4	28.9	I	15	59.2	II
5	30.5	II	16	60.5	I
6	31.3	II	17	63.5	I
7	36.1	I	18	67.0	I
8	36.8	I	19	70.1	II
9	44.0	II	20	75.1	II
10	47.3	II	21	76.5	II
11	50.0	I	22	76.8	II

Thus, a comparison of the obtained data on the average drilling time $\bar{\tau}_d$ and the time to failure of components of the hydraulic part of mud pumps ($\bar{T}_1 = 51.46$ hours), taking into account the significant scatter of the latter ($V = 0.99$), indicates an insufficient level of failure-free operation of pumps.

As noted in (Babaev et al., 2015), a schematic approach to increasing the reliability of the system under consideration is also possible by using the unloaded redundancy method, where a backup mud pump replaces a failed mud pump. However, from an economic perspective, this approach is only feasible in the most critical cases, such as when complications frequently arise during well drilling.

It is also important to use modern methods to increase the wear resistance of the working surfaces of rubber elements. The results of stand tests presented in (Salamatov, 1996) indicate the great potential of the method of diffusion surface modification of the piston cuffs of mud pumps. In addition, the widespread global use of three-piston single-acting mud pumps deserves attention, due to numerous technical and operational advantages (Babaev et al., 2018).

In general, the introduction of a new generation of technically complex rigs has generally required more qualified service support, diagnostics (Zavyalov, 2018), maintenance (MRO), and repair (R) of equipment (Babaev et al., 2022).

It is known that the composition and structure of the adopted maintenance and repair system are determined by the standard (GOST 18322-2016), which defines types and methods of maintenance and repair, including unscheduled and unregulated maintenance, maintenance under special conditions, maintenance focused on ensuring failure-free operation, etc. It is also important to include in the system maintenance that monitors the condition of the equipment, with maintenance performed under special conditions as needed (Babaev et al., 2022).

It is typical for OGFE to carry out maintenance under special conditions, for example, when addressing emergency situations arising during drilling, such as sticking and breakage of drill and casing pipes or accidents.

Maintenance is also provided to ensure failure-free operation; in this case, necessary maintenance during the operation of equipment with periodic assembly and disassembly work and transport of components from one point to another. As a rule, during the re-installation period, in order to fully restore the reliability of the equipment before it is put into operation at a new point, early (scheduled) maintenance is carried out, and, if necessary, the corresponding assembly units and assemblies are repaired (most often aggregate repair).

In the case under consideration, the number of system states increases: conditions occur when the system or some of its subsystems are in a state of re-installation, with the possibility of performing all or part of certain maintenance and repair operations. In particular, the decision on the possibility of continuing the operation of an object until the necessity of replacement (repair) of its elements is determined is made on the basis of the results of maintenance with continuous or periodic monitoring of the parameters determining the technical condition of the object (Babaev et al., 2022). These types of maintenance support high levels of operational efficiency and repairability of structures, with the use of effective diagnostic tools and non-destructive testing, as well as the development of the necessary production and technical base.

The system also utilizes combinations of maintenance and repair methods, including proprietary maintenance and repair, as well as maintenance and repair performed by specialized organizations or personnel

As noted, the proprietary method of maintenance (repair) or service maintenance (SM) is a highly promising approach, providing high-quality elimination of the consequences of failures, as well as reducing maintenance and repair costs. Pre-operational maintenance, which precedes the next cycle of operations at a new site, and operational maintenance, conducted before critical operations, are particularly important.

Conclusions

Thus, solutions aimed at reducing design, manufacturing, maintenance, and repair costs, and generally improving the quality and required reliability of process equipment, are key priorities in any modern production, oil, and gas complex.

The development of the oil and gas industry drives the oil engineering sector to produce more economical and durable oil and gas field equipment, increase the reliability and competitiveness, and further improve the manufacturing processes;

The development of technical systems follows the law of progressive evolution, reflecting modifications that address shortcomings identified during operation.

Research and analysis of the evolution of equipment used for drilling oil and gas wells made it possible to identify the main factors that influence their operational efficiency.

A number of technical areas have been identified, the development and use of which will allow new stages in the evolution of drilling rigs in the future.

References

Andriyanov A.M., Andriyanov P.A., Bur M., 2018. Drilling automation based on rigs equipped with the top drive system. *IOP Conference Series. Earth and Environmental Science*, 181(1): 10–21. DOI: 10.1088/1755-1315/181/1/012002.

Atchison B.W., Sarpangal V., 2022. Automated Well Control Versus Traditional Well Control: A Human Error Comparison Process. *IADC/SPE International Drilling Conference and Exhibition, Galveston, Texas, USA*. DOI: 10.2118/208786-MS.

Babaev S.G., Habibov I.A., Feyziev I.A., 2022. Main directions for improving the system of maintenance and repair of oil and gas field equipment. *Equipment and technologies for the oil and gas complex*, 1: 7–13. DOI: 10.33285/1999-6934-2022-1(127)-7-13.

Babaev S.G., Habibov I.A., Kerimova S.V., 2017. Graphic model of reliability forming for mechanical engineering products. *Vestnik PNIPU*, 19(2): 36–47. DOI: 10.15593/2224-9877/2017.2.03

Babaev S.G., Kerimova L.S., Guliev F.S., 2015. Main directions for increasing the reliability of high-pressure piston pumps. *Scientific notes of the Research Institute of GPOG and H. SPEKTR LLC, Baku*, 16: 300–315.

Babaev S.G., Kershenbaum V.Ya., Habibov I.A., 2018. Evolution of the quality of tribocouplings in oil and gas equipment. *NING, Moscow–Baku*, 516.

Babaev S.G., Kershenbaum V.Ya., Habibov I.A., 2020. Evolution of reliability in the "quality-competitiveness" complexes of oilfield equipment. *NING, Moscow–Baku*, 416.

Habibov I.A., Abasova S.M., 2022. Quantitative Assessment of the Risk of Failure and Vulnerability of Oil and Gas Pipelines at Underwater Crossings. *15th International Conference on Applications of Fuzzy Systems, Soft Computing and Artificial Intelligence Tools – ICAFS-2022, Springer Nature Switzerland*, 610: 330–337. DOI:10.1007/978-3-031-25252-5_45.

Kershenbaum V.Ya., 2015. RGK – Archipelago of import substitution. *NING, Moscow–Baku,* 340.

Litvin S., Gersman M., 2010. Parallel Evolutionary Lines Application for Technology Forecast. Forecasting methods based on TRIZ. *Sat. scientific tr. Library of the TRIZ Developers Summit, St. Petersburg*, vol. Z, 280.

Salamatov Yu.P., 1996. System of laws of technology development (basics of the theory of development of technical systems). *Institute of Innovative Design, Krasnoyarsk*, 136.

Vladimirov A.I., Kershenbaum V.Ya., 2009. Competitiveness in the background crisis. Oil and gas technology. *National Institute of Oil and Gas*, 696.

Zavyalov A.P., 2018. Analysis of current trends in the development of repair, technical and diagnostic maintenance systems for oil and gas production. *Equipment and Technologies for the Oil and Gas Complex*, 6: 67–72. DOI: 10.30713/1999-6934-2018-6-67-72.

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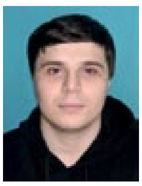

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