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# Intelligent diagnostic system of the mobile drilling rig hoisting equipments

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The hoist system and braking mechanism of the drilling drawwork of mobile drilling rigs have a significant safety impact on the technological process and its efficiency, and the economic component of their maintenance is significant during the life cycle of the rig. Recommendations have been developed for the formation of a list of controlled parameters for diagnostics of the traveling system (drilling line, hook block, crown block) and brakes of the drawwork. The functioning of such a diagnostic system makes it possible to describe the operational life cycle of the equipment, predict the condition of the equipment, develop mathematical models and maintenance strategies, evaluate their effectiveness and implement continuous improvement and adaptation of technical influences and use of the equipment taking into account its actual condition

**Keywords:** mobile drilling rig; diagnostic system; technical operation; maintenance; drilling line; brakes of the drawwork

# Інтелектуальна діагностична система спуско-підіймального комплексу мобільних бурових установок

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Нафтогазова промисловість є капіталомісткою, використовує все більш передові й складні технічні системи, де механічні, електричні, гідравлічні та інші компоненти інтегровані з програмним забезпеченням і електронікою. Водночас застосування діагностичних систем за принципом неперервного контролю та аналізу технологічних машин при їх експлуатації є сучасним перспективним напрямом розвитку техніки. Талева система та гальмівний механізм бурової лебідки мобільних бурових установок мають вагомий безпековий вплив на технологічний процес та ефективність його проведення, а економічна складова їх технічного обслуговування є значною протягом експлуатаційного етапу життєвого циклу установки. Тому в роботі розглянуто завдання розроблення методів та засобів функціонування провадження інтелектуальної діагностичної системи мобільних бурових установок на базі вимірювальної і мікропроцесорної техніки. Розроблено рекомендації щодо формування переліку контрольованих параметрів діагностики талевої системи та гальм бурової лебідки, показано взаємозалежність діагностичних параметрів з технологічними режимами роботи, запропоновано алгоритм роботи інтелектуальної діагностичної системи та її технічна реалізація на базі контролерів та датчиків. Функціонування такої діагностичної системи дає можливість описати експлуатаційний життєвий цикл обладнання, прогнозувати стан обладнання, розробляти математичні моделі та стратегії обслуговування, оцінювати їх ефективність та реалізовувати неперервне поліпшення та адаптацію технічних впливів і загалом використання обладнання з врахуванням його фактичного стану. Це не тільки підвищить ефективність експлуатації техніки за рахунок мінімізації витрат на ТОіР, зменшення непродуктивного часу, а і попередить про вірогідність виникнення помилок персоналу та потенційних нештатних (в тому числі аварійних) ситуацій

**Ключові слова:** мобільна бурова установка; діагностична система; технічна експлуатація; технічне обслуговування; талевий канат; гальма бурової лебідки

**Introduction**

The oil and gas industry is capital intensive and uses increasingly advanced and complex technical systems where mechanical, electrical, hydraulic and other components are integrated with software and electronics. Uses sensors and automation tools to manage their work and productivity, to control the technical condition and safety factor. A promising direction in the development of technology to ensure it`s reliable technical operation is the use of diagnostic systems based on the principle of continuous analysis [1]. Such systems integrated into the machine with the help of special devices diagnose the current operating conditions, accumulate the "history" of work, automatically analyze this information, give special adapted recommendations to the service personnel regarding the technical condition and the need for maintenance of the equipment.

Continuous diagnostics with data analysis is an important element of the machine operation system and management of their quality and reliability. This expands capabilities, increases productivity, reduces the risk of gradual failures, detects operator errors, provides information about the operation of equipment, reduces downtime, improves planning of the purchase of spare parts, prevents the occurrence of out-of-hours situations.

Widely used equipment in the oil and gas industry are mobile drilling rigs [2, 3] for workover operation and drilling of wells. They make up a significant share of the global fleet of drilling rigs. Functionally designed for: drilling shallow wells; drilling side shafts in wells of the old operational fund; carrying out workover operation of wells. This is especially relevant for Ukrainian oil and gas enterprises, and the safety and economy of the technological process are important components.

One of the main reserves for reducing the cost of work using mobile drilling rigs is:

– reduction of maintenance costs by moving from a system of planned and preventive maintenance to adaptive maintenance according to the actual technical condition within the life cycle cost of the rig;

– prevention and prevention of emergency situations in the process of technological operations.

Therefore, the accounting of the actual work performed by the subsystems of the rig taking into account the valid technological parameters, taking into account the real technical state of the subsystems of the rig and reliable forecasting of its changes when planning the volumes and terms of maintenance will ensure:

– orecasting changes in the actual technical condition of the equipment based on diagnostics and intelligent data analysis by built-in diagnostic tools;

– improving the quality of equipment and preventing emergency situations.

The proposed intelligent diagnostic system (IDS) of the traveling system (drilling line, hook block, crown block) and brakes of the drawwork is intended for the implementation of continuous intelligent diagnostics in the following stages: scanning the state of the machine in real time; forming a database of these data for the entire period of operation; operational signaling of personnel about a critical change in diagnostic parameters; forecasting changes in parameters and developing recommendations for carrying out technical impacts.

The use of automation tools makes it possible to obtain reliable quantitative information about the technical condition of the equipment, and as a result of its automated analysis and use, the following is achieved:

– increasing the coefficient of technical readiness of the rig;

– a significant reduction in maintenance and repair costs primarily due to forecasting the remaining resource of the equipment, fully working out its resource and optimizing the frequency and scope of these works.

**Review of the research sources and publications**

Many scientific publications highlight the issue of continuous monitoring of technological processes and the technical condition of machines in the oil and gas industry. Diagnostic systems allow control and management of technological parameters, detect malfunctions, and predict the technical condition of equipment. They provide an efficient way to find and correct machine errors and reduce the error rate of personnel.

Most scientific paper are devoted to issues of diagnosing technological processes in the well. In particular, the paper [4] systematized and studied the characteristics of a complex of oil and gas facilities using the example of industrial drilling rigs and proposed a method of coding a set of technological parameters of drilling states in the form of structured codes that carry information about the amount, time and planned economic data using the example of drilling processes. Paper [5] generally considers the topic of monitoring drilling processes and focuses on automatic detection of drilling cycles. Hardware and software solutions for data collection and automatic data analysis procedures are proposed.

The purpose of the study [6] is a monitoring system of technological parameters of drilling safety in real time. The issue of digital and intelligent diagnostics of the hoisting complex (drawwork, traveling block, crown block, drilling line) using the acoustic emission method for automatic fault detection is discussed in [7].

In publications [8, 9, 10, 11], the concepts of equipment maintenance and its impact on the efficiency of the equipment are considered. It was noted that one of the main factors affecting the quality of management of the technical operation system is the use of information technologies. It is noted that emergency recovery is much more expensive for the enterprise than preventive recovery. Moreover, preventive maintenance is more effective when adjusting it depending on the actual circumstances, data about which we receive during the operation of diagnostic systems.

Paper [12, 13] pay special attention to the comprehensive analysis of various factors affecting the quality of the maintenance and repair system, in particular at enterprises of the mining and metallurgical complex. The positive and negative factors influencing the correct choice of the maintenance and repair strategy of the equipment were determined. The main areas of work to ensure the effectiveness of maintenance and repair were identified, primarily monitoring and diagnostic support for maintenance and repair in the mode of indiscriminate evaluation of the working equipment, development of recommendations for managing the technical condition of energy and technological equipment in the "real-time" mode, development of the technical task (TOR) for the creation of systems of technical diagnostics, low-cost flexible technologies for the organization of predicted maintenance of the mechanisms of technological systems and individual units "as is".

**Definition of unsolved aspects of the problem**

The traveling system and braking mechanism of the brakes of the drawwork have a significant safety impact on the technological **process**, and the economic component of their maintenance is significant during the operational stage of the life cycle of the rig. Theefore, solving the tasks of automated control and analysis of the movement parameters of the elements of the traveling system, their interaction with the drilling line, and accounting for factors affecting the performance of the line and brakes is of significant practical importance.

Currently, the resource of the line is determined by the amount of work performed by it, which takes into account only the movement and load on the line. Work records are kept by the master of the rig according to the number of performed hoisting operations and the tolerance of the tool to the hole during drilling. And the movement accounting itself is visual, evaluative, and usually does not take into account auxiliary technological operations (lifting a column of pipes from a spider, technological runs of an unloaded thermal system, etc.). This calculation also does not take into account other operating factors of influence [14]. Currently, the manufacturer of drilling lines, when establishing the normative value of the permissible work performed by him, deliberately lays down a certain coefficient of resource reserve, determined by an expert. With this coefficient, he tries to take into account additional influencing factors. But the lack of reliable statistical information about the life of lines and accurate methods of its calculation and high safety requirements can cause an excessive supply of resources that are not used during operation.

In addition to the resource, the regulations of the labor protection system additionally establish the following criteria for rejection (regardless of its performance) - breakage of a line strand, the formation of a twist, breakage of a certain number of wires per unit length of the drilling line, a change in the shape of the line (flattening, saddle-shaped or barrel-shaped).

After the drilling line has worked out the resource set by the manufacturer (fulfillment of the normative work value) or the rejection criterion has appeared, it is bypassed. That is, re-equipment of the traveling system is taking place - a certain section with the most work is removed from the side of the used end (drum) and the equipment of the traveling system is added from the line bay (side of the dead end). At the same time, the line is integral.

The moment and length of the overpass of the traveling line significantly affects the full use of its resource and non-productive time (duration of work on the overpass). At the same time, by increasing the length of the line bypass, we use its resource incompletely, and by reducing it, the frequency of the bypass increases and unproductive time increases. By accounting for the IDS of the work of the belay line, we receive complete and reliable information about the work performed by each elemental section of the line, about each incident of the occurrence of factors of operational influence on them. Its presence will allow:

– to ensure a more complete use of the resource of the drilling line;

– to reduce the amount of non-productive time spent on the crossing by optimizing the volume and frequency of its conduct;

– to provide reliable statistical information for line manufacturers in order to establish justified values of the normative resource of the drilling line (work);

– designers of mobile drilling rigs, using the operational information obtained during design, to optimize design parameters (for example, the shape and mass-inertial characteristics of pulleys) and dynamic and kinematic parameters of the work of the hydraulic system (movement, speed, acceleration, load), to offer new types of equipment that are more will fully take into account the influence of operational factors on the operation of the drilling line;

– prevent the occurrence of emergency situations, which are extremely dangerous in case the line is broken.

The task of continuously diagnosing the technical condition of the brakes of the drawwork is also particularly important to prevent the occurrence of emergency situations. Accidents related to brake malfunctions cause serious consequences - the tool falling into the well, the moving elements of the traveling system falling onto the base of the drilling rig.

Eliminating the consequences of such accidents requires both significant funds and is long-term. In some cases, an incident may lead to a loss of the well, the cost of which is millions of US dollars. There is also a great danger of occupational injuries to personnel.

Nowadays, the wear of friction brake linings is determined by visual assessment of the residual thickness or the presence of defects, or intuitively by feeling the quality of braking. And, as is known, more than 60% of **emergency** and emergency situations arise as a result of staff mistakes. Therefore, the lack of continuous diagnosis of system health control causes the appearance of the human factor and increases the probability of accidents.

Therefore, the proposed IDS of the hoisting complex will increase the efficiency of technological operations, their safety, and save resources by reducing **maintenance** costs and non-productive time. And the availability of large arrays of received operational information will create prerequisites for improving the structures of the hoisting complex of rigs.

**Problem statement**

Implementation of IDS of mobile drilling rigs based on measuring and microprocessor technology to obtain a full range of necessary highly informative diagnostic parameters is an urgent task. This requires the development of recommendations for the formation of a list of controlled parameters for diagnostics of the traveling system and brakes of the drawwork, identification of interdependencies of diagnostic parameters with technological modes of operation, development of an algorithm for the operation of the IDS and its technical implementation based on controllers and sensors. Providing the ability to accumulate and analyze information makes it possible to describe the operational life cycle of equipment, predict the condition of equipment, develop mathematical models and maintenance strategies, evaluate their effectiveness and implement continuous improvement and adaptation of technical influences and in general the use of equipment, taking into account its actual condition.

**Basic material and results**

***Traveling system***

In order to predict the resource of the drilling line, we justify the operational factors affecting its durability and operational parameters, which are diagnosed by the proposed system. The calculation of influence factors is performed continuously for each section of the line, which is in the equipment of the line system - from the running to the "dead" line. Its total length and the movement of the strands of the line equipment are determined by the height of the tower. The properties of the line are taken into account by the following characteristics: the diameter of the drilling line $d_{dt}$, the breaking force of the line $F_{br}$, structural features (number of wires, type of core and winding, etc.).

Schematic diagrams of the equipment of the thermal system with the designation of the main structural and operational characteristics are shown in Fig. 1.

We will provide and justify the design and operational parameters of the traveling system, which affect the operation of the line.

*Factor 1. Work done when moving the line.*

This is the basic and most important operational factor, according to which the line resource is currently regulated. It functionally depends on the movement of $S$ sections of the line and the load on the hook block $F$. $Fct1 = A = f(F, S)$.

*Factor 2. Bends of the line when it passes through the pulleys of the traveling and crown blocks.*

When the line passes through the pulleys of the traveling block and the crown block, sections of the line are subjected to cyclic tensile and compressive loads from bending and cause additional stresses in the wires. There is a phenomenon of fatigue in the wires of the line, leading to loss of strength and rupture of these elements. Therefore, the method of estimating the life of line needs to take into account these industrial statistical data that account for the parameters of load cycles. In general, this strength loss factor depends on: the load on the hook block $F$, the number of bending cycles $i_{bc}$, diameters of the pulleys of the traveling and crown block of the traveling system $d_{p\,i}^{cr}, d_{p\,i}^{tr}$, the speed of movement of sections of the edging through the pulleys $V$, the multiplicity of the traveling system $i$. $Fct2 = f\left(F, i_{bc}, d_{p\,i}^{cr}, d_{p\,i}^{tr}, V, i\right)$.

a)

b)

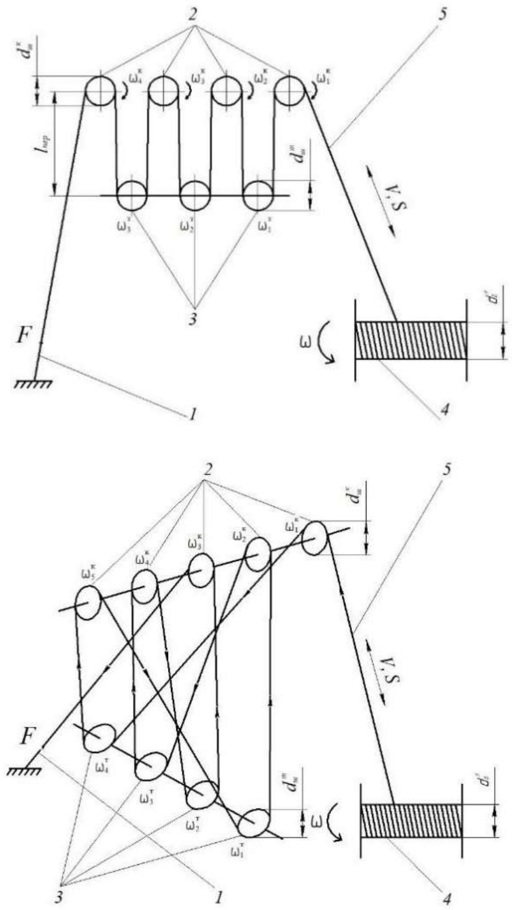


**Figure 1 – Schematic diagram of the thermal system equipment:**

a – parallel equipment, 3×4;
b – a type of cross-fitting 4×5
1 – the dead end of the drilling line;
2 – crown block pulleys;
3 – pulleys of the traveling block;
4 – drawwork drum; 5 – a line

*Factor 3. Earthing and bends of the дumy when winding-unwinding on the drawwork drum.*

In the process of lowering the tool into the well, the cable line is wound without load (ascent of an unloaded elevator), and is wound from the drum under load (descent of a loaded elevator), i.e., the line from an unstressed state in the turns on the drum passes during winding from the drum to a tense state in the leading turn. In the process of raising the column of the tool, on the contrary, the line is wound on the drum under load (lifting the loaded traveling block), and is wound without load (lowering the unloaded traveling block). At the same time, in addition to the bending of the thermal line, its turns are pinched, due to the change in the stress state during winding-winding on the drum, which causes wear of the outer wires of the line and reduces the resource. The factors affecting these processes are as follows: the load on the hook block $F$, the number of winding-rewinding cycles $i_{rw}$, the diameters of the drawwork drum $d_d^{drw}$, the frequency of rotation of the drawwork's drum $\omega$. $Fct3 = f\left(F, i_{rw}, d_d^{drw}, \omega\right)$.

*Factor 4. The non-stationary cyclic nature of the change in tension in the wires of the line.*

It is due to the discrete nature of the descent and ascent of the drill strings with their dismemberment into candles and movement "by the finger", which causes fatigue of the metal of the line. Functionally, It looks $Fct4 = f(V, F, S)$

*Factor 5 Vibration loads.*

The operation of the system "downhole tool – drilling line – derrick" is characterized by vibration. This oscillatory process is most pronounced during drilling, as well as in certain periods of hoisting operations. The resulting loads have a relatively high frequency compared to the change in the frequency of the main load ($T$ =1...8 Hz) and a change in the amplitude of oscillations (voltages) within wide limits. At the same time, the maximum ranges of dynamic forces take place in the leading and stationary branches of the line. The functional dependence of this factor is as follows $Fct5 = f(T, V, F)$.

*Factor 6. Slippage of the drilling line relative to the pulleys of the traveling block and crown block.*

At the moments of the start of the movement of the drilling line and its stop, due to the inertia of the pulleys of the traveling and crown blocks, their mutual slippage occurs. This causes local wear and thermal overheating of elementary sections of the line that were sliding. Production statistics indicate that when working with a downhole tool of the same length, which causes the system to stop and start at the same points on the line, it is the damage at these local places that causes the rejection of the line. Therefore, it is important to take it into account when evaluating the resource. Slippage is determined by the difference between the linear speeds of the line $V$ and the contact line of the grooves of each $i$-th pulley, in particular, which at the beginning or at the end of the movement rotate with a variable angular speed $\Delta\omega_{p\,i}^{tr}, \Delta\omega_{p\,i}^{cr}$. And, in addition to the speed of movement of the line and the design characteristics of the pulleys, slippage depends on the load $F$.

$Fct6 = f\left(V, F, \Delta\omega_{p\,i}^{tr}, \Delta\omega_{p\,i}^{cr}\right)$.

To establish the range of values of diagnostic parameters and technical characteristics of system sensors, the geometric and operational parameters of the thermal system as an object of diagnosis were analyzed. Table 1 shows a range of values that, in order to ensure a reserve of technical capabilities, prospects for the development of technical systems, and the possibility of emergency situations, exceed the actual values by 5...15%. They are used when choosing the element base of the diagnostic system.

The data was obtained from the analysis of a sample of 36 models of mobile drilling rigs in the load capacity range of 80...225 tons with an installed capacity of 350...1100 hp. production of countries: Canada, China, USA, Ukraine. Years of production of statistical information rigs - 1990...2020. The source information is a representative sample that reflects the long-term state of the market for the production and operation of mobile workover equipment and provides sufficient accuracy for practical purposes.

For the technical implementation of the work of the IDS cable harness system, automated instrumental measurement, collection, and processing of the following data are provided:

– tension of the fixed branch of the tow line;
– the linear speed of movement of sections of the moving line of the line;
– drawwork drum rotation frequency;
– the moment of occurrence and duration of the event (start of rotation - stop of the drawwork drum);
– the moment of onset and duration of the event (start of rotation – stop of each pulley of the center block and crown block in particular);
– the frequency of changes in vibration loads.

**Table 1 – Parameters of technical objects of the traveling system**

| № | Name | Marking | Units | Value |
|---|---|---|---|---|
| | 1. Design parameters | | | |
| | *Diameters* | | | |
| 1 | ~ pulleys of the crown block | $d_p^{cr}$ | mm | 480…860 |
| 2 | ~ pulleys of the traveling block | $d_p^{tr}$ | mm | 480…860 |
| 3 | ~ drawwork's drum | $d_d^{drw}$ | mm | 500…900 |
| 4 | ~ drilling line | $d_{dl}$ | mm | 25, 28, 32 |
| | *Number of pulleys* | | | |
| 5 | ~ crown block | $n_p^{cr}$ | pcs | 3, 4, 5 |
| 6 | ~ traveling block | $n_p^{tr}$ | pcs | 2, 3, 4 |
| 7 | Number of line | - | pcs | 6, 8, 10 |
| | *Lengths:* | | | |
| 8 | ~ drawwork drum | $l_d^{drw}$ | mm | 900….1600 |
| 9 | ~ the line of the traveling system | $l_{dl}$ | m | 300…600 |
| | 2. Operating parameters | | | |
| 1 | Max. moving of traveling block | $l_m$ | m | 37 |
| 2 | Tension of a fixed branch of the line | $F$ | kN | 10…1000 |
| 3 | Max. speed of running line | $V$ | m/s | 0…25 |
| 4 | Frequency of load change | $T$ | Hz | 1…8 |
| | *Rotational frequency* | | | |
| 5 | ~ drawwork drum | $\omega$ | $s^{-1}$ | 0…18 |
| 6 | ~ traveling pulleys (each in particular) | $\omega_p^{tr}$ | $s^{-1}$ | 0…18 |
| 7 | ~ crown block pulleys (each in particular) | $\omega_{p\,i}^{cr}$ | $s^{-1}$ | 0…18 |
| Note: those parameters that are not indicated in the table and are not measured by IDS sensors and are included in the functional dependencies of the influence factors are determined by simple well-known analytical dependencies | | | | |

In addition, optical control of the integrity of the line (breakage of a strand of line, formation of a twist, breakage of a certain number of wires per unit length of the line, change in the shape of the line (flattening, saddle-shaped or barrel-shaped, etc.).

The element base of the diagnostic system is selected from Siemens products, but it can be assembled from similar products from other manufacturers. To determine the tension of the fixed branch of the drilling line: we use a SIEMENS SITRANS P220 pressure sensor - (7M F15673DG00-16AP1Y) with a unified output signal of 4...20 mA. Pressure range 0..600 bar. It is installed in the primary conversion system of the cable bend through the piston in the hydraulic system of the primary converter. The linear speed of movement of sections of the moving strand of the line: V - calculated by the controller depending on the speed of rotation of the drawwork drum. Rotational frequency of the drawwork drum; pulleys of the alloy block, etc.; pulleys of the crown of the block, i.c. is measured by Siemens 6FX2001-4HB00 incremental encoders (1000 pulses/rev, with HTL type digital output, 10-30V supply voltage). The moment of occurrence and duration of the event "Start of rotation - stop of the drawwork drum and each pulley of the waist block and crown block in particular" are recorded by the controller by analyzing data from encoders installed on the drawwork drum and pulleys, respectively. Frequency of load change: T is calculated by the controller depending on the frequency of change of F during rig operation. Evaluation of the integrity of the line using a defectoscope of steel lines with the possibility of implementation in an intelligent diagnostic system. When choosing a Siemens SIMATIC programmable logic controller, we used the TIA Selection Tool equipment selection tool. This software product is available both for rig on a PC and in an online version through an Internet browser. For automation and measurement processing, we use the programmable logic controller SIEMENS SIMATIC S7 – 300 processor modifications - CPU 315-2 PN/DP 6ES7315-2EH14-0AB0 and a 64 KB Micro Memory Card (6ES7953-8LF31-0AA0). PS307 24V/2A 6ES7307-1BA01-0AA0 power supply unit with 230V supply voltage, 24V DC output provides power for the controller and expansion modules.

For signal critical messages, we introduce a sound and visual notification system on the driller's console. Output warning signals of the system are generated in the event of the following events:

– critical damage to the cable (according to the results);

– the resource of the traveling system needs maintenance;

– exceeding the permissible load on the traveling system.

To do this, configure the extension modules:

– SIMATIC S7-300, SM 323, input-output module of discrete signals with galvanic isolation of external and internal circuits, 16 inputs = 24V and 16 outputs = 24V / 0.5A - used to display light and sound notifications on the control panel;

– SIMATIC S7-300, SM 331, analog signal input module: with galvanic isolation of external and internal circuits, 8 inputs ±5V / ±10V / 1...5V / ±20mA / 0(4)...20mA, 16bit (55ms) – used for processing analog signals from the pressure sensor and defectoscope;

– SIMATIC S7-300, FM 350-2 (6ES7392-1BM01-0AA0) functional module for processing data from encoders, has two input channels, so it is necessary to use them in the amount of 4 pcs. Encoders are connected via a 20-pin front plug (6ES7392-1BM01-0AA0).

The resource algorithm of the intelligent diagnostic system of the line of the towing system is as follows. Guided by the given initial data, the measured parameters, the proposed IDS calculates the performed work $Fct1=A$ by each elemental section of the line in the equipment of the mobile drilling rig and additionally takes into account the importance of the influence of the following factors:

– $Fct2$ – the number and radius of bends, the speed of the bending cycle, the tension of the line when passing through the pulleys;

– $Fct3$ – the number and radius of bends, the speed of the bending cycle, the tension of the drilling line when winding on the drawwork drum;

– $Fct4$ – duration of cycles and values of high/low loads on the thermal system during hoisting and auxiliary technological operations;

– $Fct5$ – frequency of longitudinal vibrations of the drilling line during drilling;

– $Fct6$ – the path and speed of the slip line along the pulley, taking into account the load.

These data are visualized both numerically and graphically with the output of information on the computer screen and printing device. Combined graphic dependences of the influence of factors on the elementary sections of the line of the belay line at a certain moment of time and accumulated during its operation are built. Fig. 2 shows such a conventional idealized graph, which shows the nature of the influence of factors on the resource of sections of the drilling line.

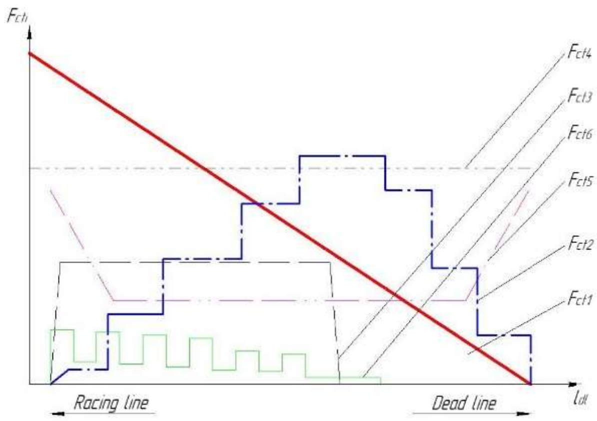


**Figure 2 – Conditional idealized graphical dependence of influencing factors on the elementary sections of the line of the traveling system**

(F – influencing factors, the scale of the axis is different for each factor)

Taking into account the weighting factor of each of the $k_i$ factors, the equivalent actual length of the line is determined. $Fct_{eq} = \sum_{i=1}^{6} Fct_i \times k_i$. The coefficient of gravity is established based on the results of experimental studies of changes in line strength under the influence of certain factors. Having accumulated a volume of statistical information, the IDS, using diagnostic data, calculates the results and predicts the length and moment of the line crossing. A generalized characteristic view of this graphical dependence for determining the bypass length is presented in Figure 3.

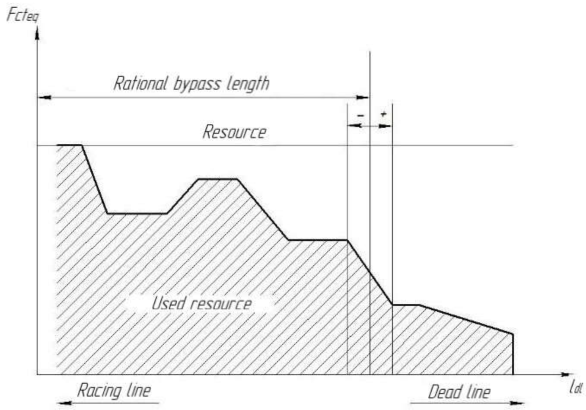


**Figure 3 – Conventional generalized characteristic view of the graphical dependence of the exhausted equivalent resource on the length of the line of the traveling system**

As can be seen in the graph (Fig. 3), the part of the tow line from the side of the running end performs more work, and the character of the broken curve is not uniform, it has certain peaks in the places of local action of individual factors. According to the nature of the curve, we determine the rational length of the line overpass. After skipping the entire length of the drilling line in the equipment, we significantly underuse the resource of the right part of the line (the area above the graph to the height of the maximum $Fct_{eq}$ value). Skipping minor areas significantly increases non-productive time - the duration of skipping. The calculation of the rational length of the line bypass is determined by the length of the line, on which the equivalent overhang exceeds the value specified by the expert (for example, a value in the range of 0.3...0.4 from $Fct_{eq}$). The exact value of this value is established by economic calculations, comparing the cost of the incompletely used resource of the removed section of the line and the cost of bypassing (the cost of non-productive time). And taking into account the performance of production tasks. Additionally, the technological parameters of the following technological operations are entered, allowing to predict the time of occurrence of the next events of line crossing with determination of the length. The system corrects them, taking into account the discrepancy between the set technological parameters and the actually measured diagnostic ones. This will ensure rational working out of the line of the thermal system, minimize costs and prevent accidents.

***Brakes of the drawwork***

The main brakes of the drawwork of mobile drilling rigs are of the friction type. They serve to brake the rotation of the drawwork drum and the movement of the elements of the traveling system until they come to a complete stop.

If earlier a strip-pad structure of friction brakes was used, now, on mobile drilling rigs, the use of disc brakes is increasingly prevalent. By implementing a system for diagnosing the technical condition and recording the operation of these brakes with an intelligent information processing system, we will receive complete and reliable information about the technical condition and resource forecast of the brake pads and the system in general. The use of such a system will ensure continuous monitoring of the condition of the brakes, full use of the resource of quickly wearing friction linings, their efficiency and will prevent the occurrence of emergency situations related to brake malfunctions.

The necessary initial information about the brake system and diagnostic parameters to be measured (Table 2) and the schematic diagram (Fig. 4) are given below. All diagnostic parameters are selected taking into account their high informativeness and simplicity and accuracy of measurements.

**Table 2 – Diagnostic parameters of disc brakes**

| № | Name | Physical quantities of measurements | | |
|---|---|---|---|---|
| | | Marking | Units. | Range |
| 1 | Pressure in the hydraulic system of the rig (brake pad drive) | $P$ | MPa | 8…18 |
| 2 | The frequency of rotation of the brake disc | $\omega$ | $s^{-1}$ | 0…18 |
| 3 | A braking torque | $M_{br}$ | kNm | 0…80 |
| 4 | The duration of the braking cycle | $t$ | s | 0…300 |
| 5 | Stroke of the rod | $l$ | mm | 5…40 |

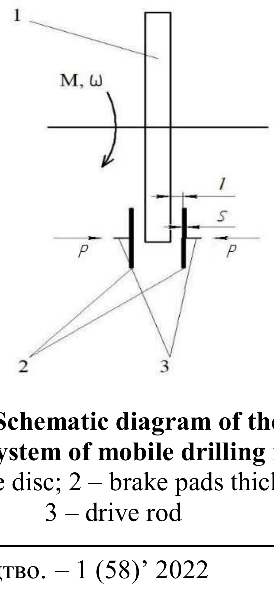


**Figure 4 – Schematic diagram of the disk-type brake system of mobile drilling rigs**

1 – brake disc; 2 – brake pads thickness S; 3 – drive rod

The diagnostic system provides control of a number of operation parameters of the main brakes of the drawwork.

*Parameter 1 - Wear of friction linings of brake pads.*

The initial stroke length of the brake pads is equal to the initial gap $l_{st}$ between them and the brake disc. As the pads wear, the stroke length increases by the amount of their wear $l_t = l_{st} + l_w$.

Manufacturers set a limit value of wear $[l_w]$, the achievement of which requires the replacement of brake pads. That is, when the event $l_t = l_{st} + [l_3]$ occurs, i.e., an increase in the stroke length of the rod to this value, the system signals the need to replace the brake pads. The driller is informed about this by a red light signal with a characteristic brake symbol; and may also be accompanied by a sound signal. After the rig is stopped by personnel, it will not "start" again until zero of the diagnostic system by a responsible person after replacing the pads. However, in order to warn the staff about the need to replace the pads in the near future, we additionally set the signal value of the controlled stroke length - $(l_{st} + k \times [l_w])$. Here $k$ is the coefficient of advance warning about the possible occurrence of an event in the near future. Let's assume $k$ =0.95, that is, the remaining resource is 5% of the initial one, at which a light signal (for example, yellow) is given. In this way, we ensure a margin of time for ordering and delivering a set of new brake pads.

Thus, by diagnosing the wear of friction linings of brake pads, we ensure the full use of their resource and prevent work with an excessively worn unit, which is dangerous.

*Parameter2. Braking moment*

Braking torque depends not only on the pressing force and contact area, but also on the frictional properties of the material of the brake linings. The frictional capacity, and accordingly the braking torque, decreases in a number of cases:

– ingress of atmospheric moisture (rain, fog, dew) – is eliminated by drying the linings by braking the system in an unloaded state at minimal movement speeds;

– ingress of lubricating process fluids on the contact surface – is eliminated by cleaning from oily contamination;

– long-term work under certain technological modes that cause changes in the properties of the surface layer of surfaces - eliminated by cleaning the surfaces or replacing the brake pads;

uneven wear of the brake pads or brake disc - is eliminated by replacement.

If the last two factors occur gradually, the first two are sudden.

And a critical reduction in the ability to brake can lead to an accident. That is why, usually, before starting work, the brake rig is tested by "idle running of the unloaded traveling system" until an intuitive feeling with a drill of the proper performance of the brakes. Only after that they start working with a loaded thermal system. However, this is again a human factor, the lack of clear values, the need for significant experience in the staff, etc.

Therefore, the registration and accumulation of information about the braking torque, which is determined based on the dependence, is relevant. The magnitude of the braking moment depends on geometric and operational factors and must be higher than the permissible $M_{br} = f(\omega, F_p, A, \mu) \geq [M_{br}]$. Here is the rotation frequency of the drawwork shaft; $Fp$ is the force of pressing the pads to the brake disk, calculated using the measured value of pressure in the drive hydraulic system of breaks $P$; $A$ – contact area; $\mu$ – coefficient of friction of materials.

The calculated intensity of the reduction in the frequency of rotation of the brake disk, depending on the rest of the specified values, characterizes the frictional ability of the linings and, accordingly, the braking torque developed by the system.

In the case of a reduction of the braking torque below the permissible level, $M_{br} < [M_{br}]$, the operator is given a signal about the inadmissibility of working with a loaded towing system. It indicates that when testing or drying the system, move only the unloaded system at minimum speed. After eliminating the malfunction, the system independently notes the increase in braking torque and removes the danger signal.

*Parameter 3 Performance of the brake drive*

The amount of hydraulic energy at the input to the executive mechanism of the brake hydraulic drive is a significant parameter that characterizes performance. If it falls below the P<P value set by the manufacturer, which is determined by the pressure control sensor, a light and sound signal about the lack of pressure in the brake hydraulic system is sent to the driller's control panel. This prevents the brakes from failing for this reason and causing emergency situations

In addition to continuous diagnostics of the technical condition of the brakes, the accumulation of information provides the conditions for calculating and visualizing the following information for management personnel:

– prediction of the remaining service life of the brakes based on the actual working time, its adjustment depending on the operating conditions;

– comparison of the effectiveness of the use of brake linings made of different materials at different technological modes of operation.

The element base of the diagnostic system, as in the previous case, is selected from the products of the Siemens company, and can be completed with similar products from other manufacturers. To measure the parameter P (pressure in the brake hydraulic system) using the SIEMENS SITRANS P DS III absolute pressure sensor. These are digital pressure transducers, characterized by a friendly interface and high accuracy. Parameterization is performed using the control buttons or via the HART, PROFIBUS PA or FOUNDATION Fieldbus interface. Nominal measuring range from 1 to 700 bar. The output signal is transmitted via interfaces or as an analog signal of 4 ... 20 mA. The frequency of rotation of the brake disc is measured with an incremental encoder Siemens 6FX2001-4HB00 (1000 pulses/rev).

The $M$ torque sensor is a T40FM torque meter with digital data transmission. Braking cycle duration: t – calculated by the controller. To control the stoke value of the rode, a non-contact sensor BERO 3RG4 is used. It serves to determine the mechanical position of metal objects by issuing the appropriate electrical signal. These signals are processed in a programmable logic controller (PLC). Signal processing of this system is also carried out by the SIMATIC S7 - 300 processor modification controller - CPU 315-2 PN/DP.

This IDS has great possibilities of expansion and extension to other technical subsystems of mobile drilling rigs. After development, implementation and approval, the following development directions can be proposed as the following steps:

– Spatial orientation of the chassis of the mobile rig during drilling on the well for accurate centering of the axis of the tower relative to the wellhead. After all, the eccentricity of the rig will cause friction of the tool on the inner walls of the mouthpiece equipment and the walls of the casing strings. Heavy wear will occur, which can cause the wellhead equipment to fail and the well string to leak. The latter is a complex accident, the consequence of which may be the liquidation of the well. Such a system will facilitate the work of the personnel, reduce the errors of placing the chassis, prevent unproductive loss of time by speeding up the rig, and reject the human factor of errors. Improve the quality and efficiency of work in the well.

– Wind load control system on the tower. Direct determination of the load index on the tower by measuring the tension of the guy wires and comparing the values on the paired branches will contribute to more accurate prevention of the occurrence of excessive loads, expand the range of wind loads that the tower can perceive, and prevent the danger of its loss of stability.

The proposed diagnostic monitoring using IDS is based on the principles of indiscriminate assessment of the technical condition of objects without decommissioning them by control means. This concept of adaptive reliability assurance provides the technical operation system with objective information about the actual work performed, the current technical condition, comparison with the previous history, and performance forecasting. It provides procedures for:

– automated multi-channel collection of parametric information about operational conditions and equipment operation processes;

– automated processing of information using processors;

– comparison of current diagnostic information with history;

– interpolation and extrapolation of object states;

– emergency signaling when approaching the maximum allowable states;

– formation of flexible equipment maintenance regulations;

– technical documentation of information about the technical condition and forecast for the future;

– long-term storage of diagnostic information and analysis of this data.

This will provide a departure from the use of a system of scheduled and preventive repairs, in which the development of maintenance and repair regulations with pre-fixed moments and volumes of technical service is not adequate to the actual technical condition of the equipment and creates organizational conditions for incomplete use of the equipment, according to the estimates of various authors, only by 30-90% of its individual resource.

**Conclusions**

The method and means of monitoring the processes of operation of the technical systems of the mobile drilling rig are proposed - the intelligent diagnostic system (IDS) of mobile drilling rigs based on measuring and microprocessor. IDS ensures the efficiency of equipment operation by implementing adaptive operation strategies "according to condition" and "according to actual earnings". The transition to such alternative strategies of operation prevents failures of technological systems and the most important equipment in a timely manner, provided the maximum possible working time before failure is ensured.

The goal is achieved by solving the IDS of the following tasks:

– instrumental monitoring of parameters of functioning and operation in combination with analysis of dynamic parametric models of failures of technical objects in real time;

– continuous diagnosis of the technical systems of machines and assessment of their technical condition by indiscriminate methods;

– forecasting of the resource with the detection of emergency and dangerous conditions;

– substantiating the scope and periodicity of maintenance based on diagnostic control data.

For this, recommendations have been developed on the formation of a list of controlled parameters for diagnostics of the traveling system and brakes of the drawwork, the interdependence of diagnostic parameters with technological modes of operation has been proposed. The technical implementation and algorithm of the intelligent diagnostic system is proposed, which has great prospects for expanding its use in other technical subsystems of the mobile drilling rig and monitoring the performance of many technological operations.

After accumulating an array of production statistical information, the system should be expanded with a second, adaptive self-learning circuit for processing diagnostic information.

The implementation of such an IDS will increase the efficiency of equipment operation by minimizing maintenance costs, reducing unproductive time, preventing operator errors and potential abnormal (including emergency) situations.

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