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Methods for Monitoring and Diagnosing the State of Sucker-rod Pumping Equipment

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Abstract. *There are plenty ways to enhance the efficiency and extend the life of downhole sucker-rod pumping units, one of the vital ones is timely diagnostics, monitoring of downhole sucker-rod pumping units. There are two widespread methods to monitor the operation of downhole pumping units: dynamometry and wattmetry. One of the effective ways of monitoring is dynamometry, which provides complete information about the state of underground equipment and enables to evaluate the operating mode of the well. Dynamometry is mostly used for monitoring and obtaining information on the condition of downhole equipment and underground pumping units. Dynamograms are recorded with dynamographs, which include force and position sensors to measure the load on the polished rod and obtain data on the movement of the polished rod. Wattmetry is applied to monitor the surface equipment of rod and well pump units, represents the dependence of the power consumed by the pump motor or the power of the unit on time. The article describes the methods of monitoring and diagnosing the operation of sucker rod and well pumping equipment, as well as reviews of modern methods of monitoring the operation of these units.*

Keywords: *monitoring, rod deep-well pumping unit, dynamometry, wattmetry, dynamogram, wattmetrogram.*

Introduction

The use of rod-and-well pumping units (RWPUs) is the oldest and most common method of oil production. The use of rod-and-well pumping units during well operation is reasonable in the final phase, when the value of natural reservoir pressure has decreased or when it is not impossible to operate by artificial method, etc. [1].

Recently, the drop in demand for fuel due to the pandemic and the war in Ukraine has caused a crisis in the oil industry. Oil producing countries, including Kazakhstan, are forced to reduce oil production in order to prevent a drop in oil prices. This will inevitably lead to the suspension or complete shutdown of about 30% of the wells of their total number. Since 85% of Kazakhstan's well stock consists of dry wells, the shutdown of 30% of wells would severely affect the normal, uninterrupted operation of producing wells, in particular their equipment and facilities.

As shown in Figure 1, in the oil fields of Kazakhstan, sucker-rod pumping is the major method of oil production. Roughly 85% of all wells are operated by sucker-rod pumps, 13% of wells are developed using an electric submersible pump, and the remaining 2% are other methods of oil production (hydraulic pumps, etc.).

The tubing string pump units (Figure 2) are a set of underground equipment: borehole pump (1), tubing string (2), column of pump rods (3) and surface equipment: polished rod (4), wireline suspension (5), wellhead fittings with wellhead gland (6), pump jack (7).

Methods and materials

There are numerous methods to enhance performance and extend the service life of downhole

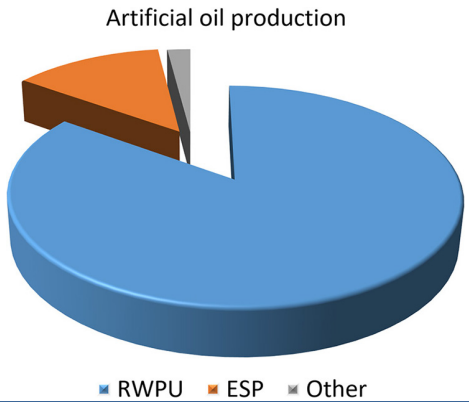
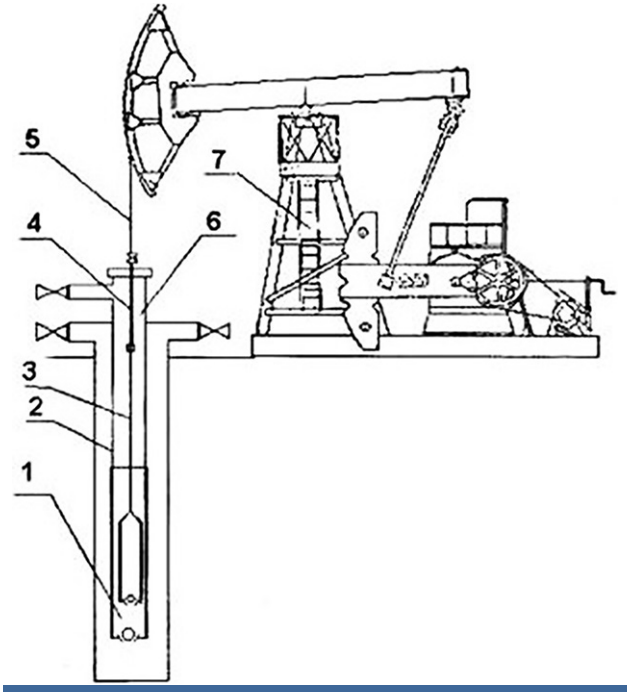


Figure 1 – Statistics of artificial methods of production in Kazakhstan



1 – borehole pump, 2 – tubing string, 3 – column of pump rods and surface: 4 – polished rod, 5 – rope hanger, 6 – wellhead fittings with wellhead gland, 7 – pump jack

Figure 2 – RWPU general scheme

sucker rod pump units, one of the most significant of which is timely diagnostics, monitoring the operation of the sucker rod pump unit.

There are two widespread ways to monitor the operation of downhole sucker rod pumping units: dynamometry and wattmetry. Dynamometry is applied for monitoring, mainly for monitoring and obtaining information about the condition of downhole equipment, underground pump units [2]. Wattmetry is conducted for monitoring of above-ground equipment of the RWPU.

Dynamometry. One of the efficient methods of monitoring is dynamometry, the construction of a dynamogram, which gives complete information about the state of the underground equipment and allows to assess the operating mode of the well [3]. The dynamogram is captured by dynamographs, which contains force and position sensors to measure the load on the polished rod and get the data about the movement of the polished rod.

The theoretical dynamogram is a parallelogram on a graph with axes: P is the polished rod load, S is the movement of the polished rod (Figure 3). At point A, the plunger is at BDC (bottom dead center), there is no fluid friction and corresponds to the statistical weight of the rod. Consequently, the friction of the tubing column against the fluid reduces the length of the plunger stroke and the exhaust valve closes at point A1, not at A. At point B1 the load on the rod is equal to the sum of the weights of the fluid column and the rods, at that point the discharge valve opens and the fluid flows into the pump cylinder. The further stroke of the plunger is described by the line B1-C1. At C1 the plunger is at TDC (top dead center) and the suction valve is closed. As the downward movement begins, the friction force changes, the load change corresponds to line C2-E2 with the unloading of the tubing column. Point E is the opening of the discharge valve, line E-A describes the downward movement of the plunger.

The dynamogram varies depending on the plunger fit, changes in load parameters, gas influence (Figure 4, I), turning of the boom, plunger, discharge and suction valves (Figure 4, II), in case of clogged valves (Figure 4, III), etc. The boom rupture is indicated on the dynamogram by the load difference during the up-and-down movement, the dynamogram in this case will have the form of a narrow loop [4].

Dynamograms describe about 35 parameters of RWPU state, determine the dynamics of quantitative and qualitative indicators, which allows to effectively operate wells with minimal undercutting and the least losses due to timely monitoring.

The real dynamometer map differs from the theoretical one mostly due to the influence of inertial forces and oscillation processes in the sucker-rod string. As a result of the influence of inertia force, the dynamogram is rotated by a certain angle clockwise, and longitudinal oscillations in the sucker-rod string cause wave-like changes in the load on the wellhead rod.

The size and shape of the actual dynamogram are determined by the length of the polished rod stroke and the forces acting on it, which in turn depend on the depth of descent and pump diameter, the frequency of oscillations and the nature of disturbances in the underground equipment or hydrostatic load on the plunger.

Comparison of the dynamograph dynamogram with the theoretical dynamogram allows finding out deviations from the normal operation of the unit as a whole and defects in the operation of the RWPU itself. Regular inspection of the RWPU is mandatory, since it enables to prevent more serious complications in time. The dynamogram, in addition, allows to specify the pumping mode and to improve it if possible.

Wattmetry. The wattmetry method is grounded in taking values of consumed power in relation to time [5]. Advantage of this method is the simplicity in installation, in measurements, possibility of the account of consumption of the electric drive.

This method began to apply the first dynamograms at diagnostics of RWPU. The first algorithms of the analysis of wattmetrograms were developed and presented in works Krichke V.O. [5], nevertheless development in this area was restrained by limited possibilities of controllers.

The wattmetrogram is a dependence of power, consumed by the pump motor or power of the installation on time (Figure 5).

The wattmetrogram of a fully balanced and functioning rocking machine has two half-periods for each full stroke of the rod, with peaks corresponding to the horizontal positions of the crank.

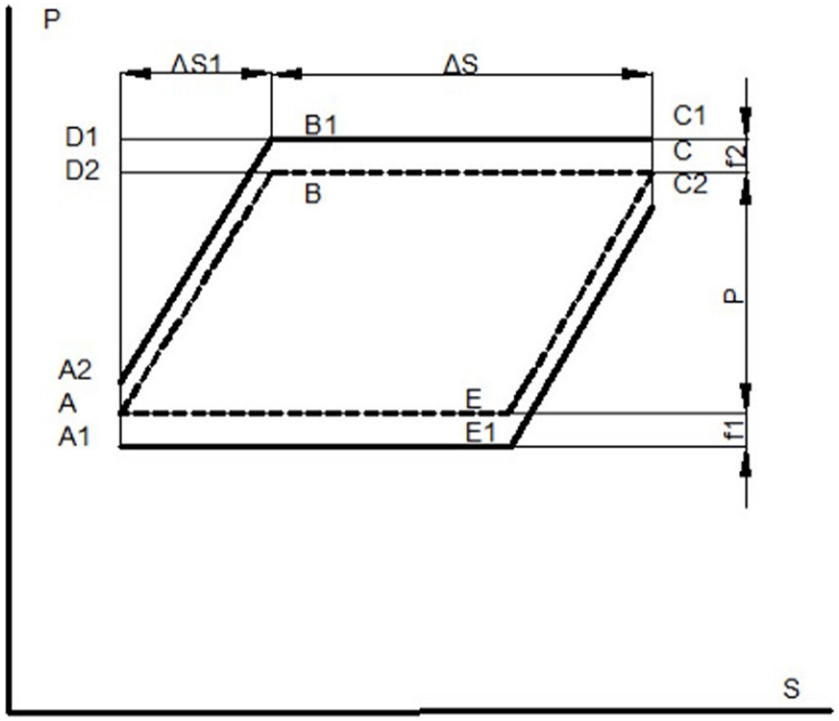


Figure 3 – RWPU dynamogram

Figure 4 – Dynamograms examples

The difference in the maximum values of power consumed by the drive motor of the deep pump rod should not exceed 10% [6].

Analysis of wattmetrograms enables to control the condition of rod well pumping units. By using wattmetrograms the efficiency of the pumping machine can be estimated, as well as its equilibrium [7].

Wattmetering gives the possibility to detect the following electric motor faults: current overload, phase imbalance, supply voltage frequency deviation, etc.

The wattmetrogram provides real-time monitoring of faults such as: rod breakage, defects in the mechanical drive, namely runout in the gearbox, unbalanced counterweights, defects in both discharge and suction valves, gushing manifestations in wells, belt breakage and slippage, polished rod and plunger faults [Figure 6].

The analysis of the wattmetric spectrum will be useful in determining the vibration and shock loads, which enables us to diagnose defects in the bearings and the gearbox.

The primary benefits of wattmetering over

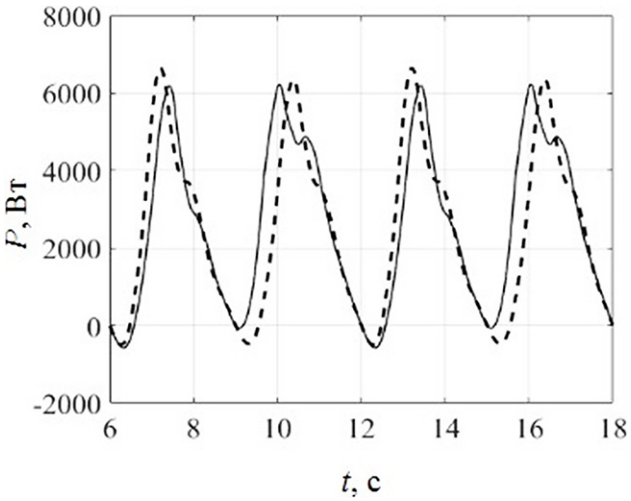


Figure 5 – RWPU wattmetrogram

a competing method of diagnostics, namely the dynamometer method, are:

- relatively small number of sensors (current and voltage transformers);
- possibility to measure electric energy consumed

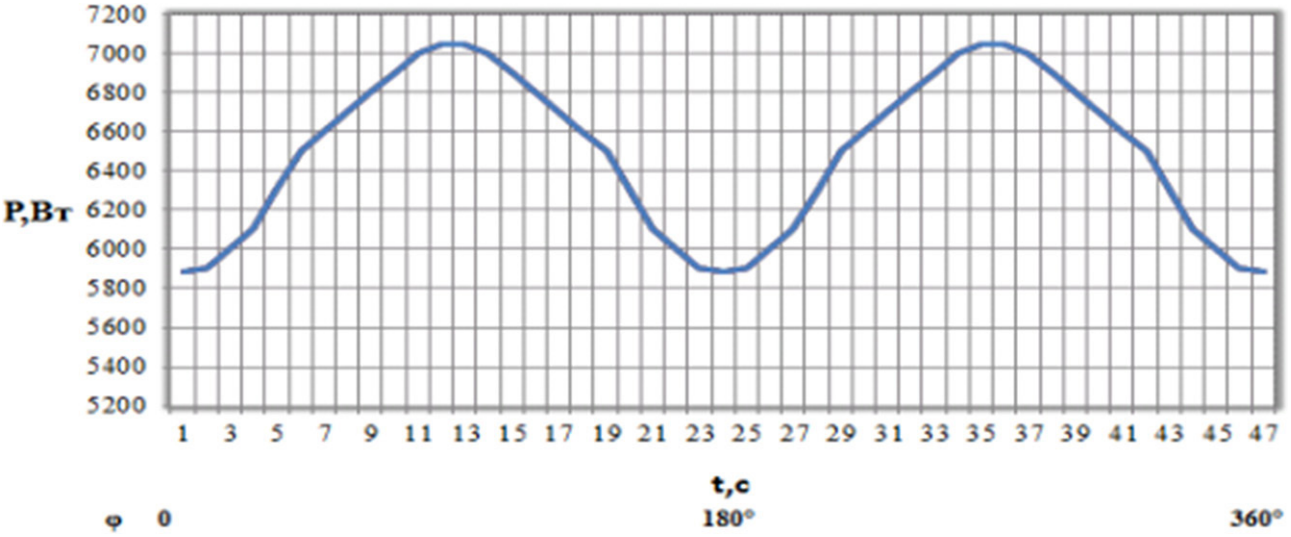


Figure 6 – Wattmeterogram under normal operation of the unit

by the drive;

- possibility of integration with automated systems of technical and commercial electric power accounting.

As it was already mentioned above, the method of wattmetering is a reliable and trustworthy method of diagnostics of RWPU, which provides not only its underground part of the pump installation, but also the ground part, such as a dynamogram.

Development of the dynamogram by means of wattmetering and the modern computer equipment will enhance efficiency of both methods, from the side of wattmetering it a simplicity of installation, the minimum quantity of gauges and more profound analysis of failures by means of a spectrum of wattmetrograms, and from the side of dynamometric it is development of the given theme. Altogether, the resulting method of equipment diagnostics has advantages over other non-destructive diagnostic methods.

Results

It is required to start from the measured parameter during the wattmetrogram analysis. Thus, for example, to assess the shock and vibration loads a three-dimensional image of the spectrum of wattmetrograms should be built up (Figure 7). In the absence of shocks, the three-dimensional spectrum has a flatter and smoother appearance. «Convex» areas are characterized as the difference between the energy consumed from the mains or expended to lift the plunger and fluid and to lift the counterweight and the energy expended to overcome friction.

Diagnostic features of breakage in the pumping column of pipes are growth of peak values on the wattmetrogram, as well as defects of the suction valve of the submersible pump are revealed. By analyzing the spectrum of wattmetrogram of power consumption in electric motors, faults in the electric part of the rotor, electric part of the stator, defects in the bearings can be discovered.

By the nature of changes in the spectrum of the power signal defects in the gearing, gears on the shaft are determined. Wattmetering also enables to assess the balance of the work, calculate the efficiency of the RWPU.

Conclusion

In the article the review on modern methods (dynamometry, wattmetry) of monitoring the rod deep-well pump units operation is given.

One of the effective methods of monitoring is dynamometry, the construction of a dynamogram, which gives complete information about the state of the underground equipment and allows to assess the operating mode of the well.

By analyzing the wattmeter spectrum of energy consumption in electric motors, faults in the electric part of the rotor, electric part of the stator, bearing defects can be detected. Wattmetering also makes it possible to assess the balance of operation, to calculate the efficiency of the RWPU.

The analysis of wattmetrograms allows to control the condition of sucker-rod well pumping units. With the help of wattmetrograms it is possible to calculate the efficiency factor of the rod pumping unit, as well as its balance. To determine vibration and shock loads, we can use wattmetrogram spectrum analysis to diagnose bearing and gearbox defects.

The construction of a dynamogram with the use of wattmetry and modern computer equipment will enhance the effectiveness of both methods. On the wattmetry side, this is an easy installation, the minimum number of sensors and a deeper analysis of faults using the spectrum of wattmetry, while on the dynamometer side, this is the development of this topic.

Taken together, the resulting method of equipment diagnostics has advantages over other non-destructive diagnostic methods.

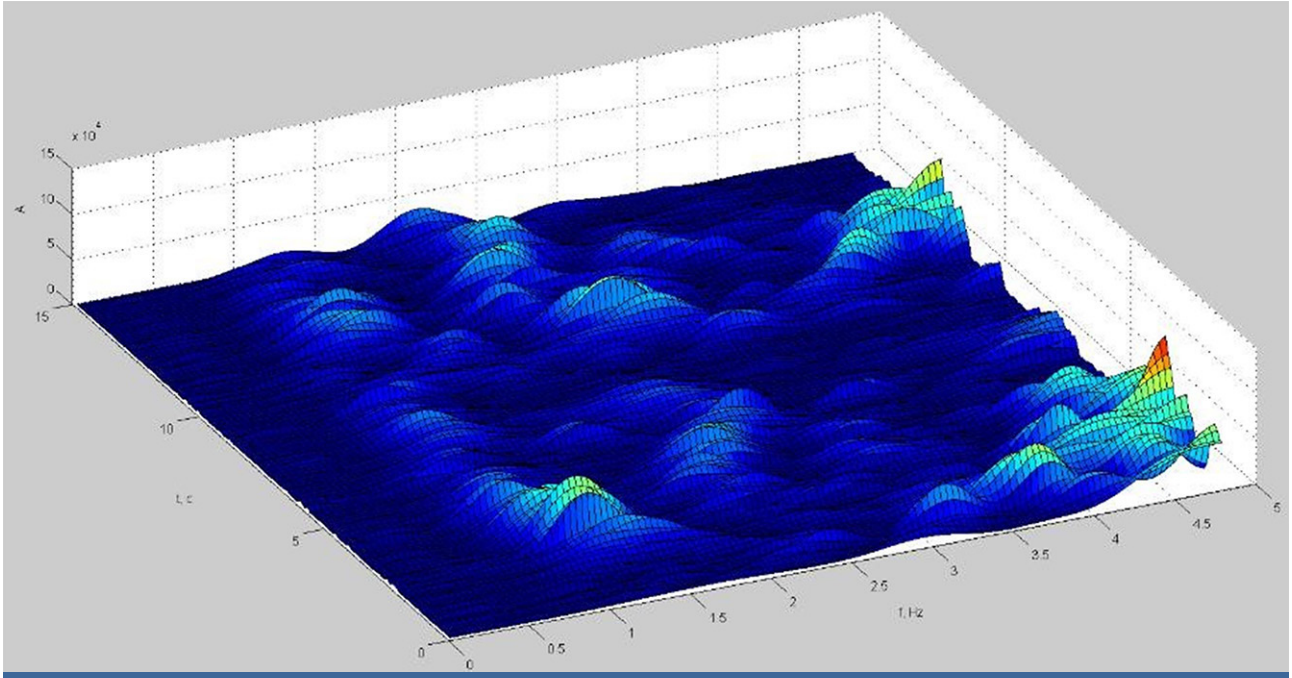


Figure 7 – Three-dimensional spectrum of the wattmetrogram

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Штангалық-ұңғыма сорғы қондырғылары техникасының жай-күйін сараптау және диагностикалау әдістері

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Аңдатпа. *Штангалық-ұңғыма сорғы қондырғыларының тиімділігін арттырудың және қызмет ету мерзімін ұзартудың көптеген жолдары бар, олардың маңыздыларының бірі-штангалық-ұңғыма сорғы қондырғыларының жұмысын уақтылы диагностикалау, бақылау. Штангалық-ұңғымалық сорғы қондырғыларының жұмысын бақылаудың екі кең таралған әдісі бар: динамометрия және ваттметрия. Бақылаудың тиімді әдістерінің*

бірі-динамометрия, жер асты жабдықтарының жай-күйі туралы толық ақпарат беретін және ұңғыманың жұмыс режимін бағалауға мүмкіндік беретін динамограмма құру. Динамометрия негізінен кенжар жабдығының, жерасты сорғы қондырғыларының жай-күйін бақылау және ақпарат алу үшін қолданылады. Динамометрия негізінен кенжар жабдығының, жерасты сорғы қондырғыларының жай-күйін бақылау және ақпарат алу үшін қолданылады. Ваттметрия штангалық-ұңғымалық сорғы қондырғыларының жер үсті жабдықтарын бақылау үшін қолданылады, бұл сорғы қозғалтқышы тұтынатын қуаттың немесе қондырғы қуатының уақытқа тәуелділігі. Мақалада штангалық-ұңғымалық сорғы қондырғылары техникасының жұмысын бақылау және диагностикалау әдістері, сондай-ақ осы қондырғылардың жұмысын бақылаудың заманауи әдістеріне шолулар сипатталған.

***Кілт сөздер:** мониторинг, штангалық тереңдік сорғы қондырғысы, динамометрия, ваттметр, динамограмма, ваттметрограмма.*

Методы мониторинга и диагностирования состояния техники штанговых скважинных насосных установок

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***Аннотация.** Существует множество способов повышения эффективности работы и продления срока службы штангово-скважинных насосных установок. Одним из важных являются своевременное диагностирование и мониторинг работы штангово-скважинных насосных установок. Есть два распространённых способа мониторинга работы штангово-скважинных насосных установок: динамометрия и ваттметрия. Одним из эффективных способов мониторинга является динамометрия, построение динамограммы, которая даёт полную информацию о состоянии подземного оборудования и позволяет оценить режим эксплуатации скважины. Динамометрия используется, преимущественно, для мониторинга и получения информации о состоянии призабойного оборудования, подземных насосных агрегатов. Динамограмму снимают с помощью динамографа, в составе которого есть датчики усилия и положения для измерения нагрузки на полированный шток и получения данных о перемещении полированного штока. Ваттметрия применяется для мониторинга наземного оборудования штангово-скважинных насосных установок, представляет собой зависимость мощности, потребляемой двигателем насоса, или мощности установки от времени. В статье описаны методы мониторинга и диагностирования работы техники штангово-скважинных насосных установок, также обзоры на современные методы мониторинга работы этих установок.*

***Ключевые слова:** мониторинг, штанговая глубинная насосная установка, динамометрия, ваттметрия, динамограмма, ваттметрограмма.*

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