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ASSESSMENT OF LOAD OF BEAM-BALANCED PUMPING UNITS BY ELECTRIC MOTOR POWER INDICATORS

Dmitriy I. SHISHLYANNIKOV, Aleksandr A. RYBIN
Perm National Research Polytechnic University, Perm, Russia

The results of experimental studies on the loading of beam-balanced pumping units (BP) of sucker rod-pumping equipment (SRPE) are presented. It is noted that the key factor that has the most significant effect causing the SRPE failure is the balance of the beam pumping unit, which determines the amount of specific energy consumption for the rise of reservoir fluid and the level of dynamic loads on the machine units. The urgency of using software-recording systems for estimating the loading of units of oil field pumping installations is substantiated. The principle of operation and design of the «AKD-SK» software recording system is described. The prospects of using this method for controlling the performance parameters and evaluating the technical state of the sicker rod-pumping units is proved on the basis of an analysis of the magnitude and nature of the changes in the loads of drive motors determined by the registration of the instantaneous values of the consumed power. The main provisions of the methodology for analyzing the watt-meters of drive motors of the sucker rod-pumping units are outlined. The nature of the manifestation of the main defects of submersible pumps and beam-balanced pumping units is described. The results of pilot-industrial tests of the beam-balanced pumping units equipped with advanced permanent magnet motors and intelligent control stations are presented. It is proved that the use of permanent magnet motors allows to reduce the specific energy consumption for the rise of reservoir fluid, which increases the efficiency of the SRPE.

However, the presence of transient processes and generator operating modes of the permanent magnet motors results in the occurrence of significant dynamic loads, which, due to the rigid fixing of the rotor of magnet motor on the reducer shaft, negatively affect the life of the gearbox bearings. It has been shown that the lack of its own bearings in the tested motors causes a high probability of engine jamming when bearing operation is disrupted and the radial beats on the drive shaft of the beam pumping unit gearbox appear.

***Key words*:** sucker rod-pumping unit, beam-balanced pumping unit, load, balancing, electric motor, software recording system, resource

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Introduction. For oil-producing enterprises, the tasks remain to ensure reliable and efficient operation of oilfield pumping equipment, reduce the costs of its operation, maintenance and repair. The solution of problems of increasing efficiency of application of the pumping unit is possible through the use of automated systems for monitoring their operational loading and assessing their technical condition. Such systems should include methods for analyzing recorded data, algorithms for preventing accidents, a system for warning of abnormal course of events in different processes with the formation of appropriate technical solutions or recommendations, which can be further used for taking required actions [8-9, 16].

Currently, in the oil fields of Russia and CIS countries, the vast majority of oil wells are operated using the sucker rod-pumping units, equipped with a mechanical drive – a beam-balanced pumping unit. The design of the installations has not changed fundamentally for more than 40 years.

The advantages of the sucker rod-pumping units with a mechanical drive are the following:

– operation during quite a long period of time;

– the possibility of using rod pumps on low-yield wells under complicated geological conditions (a large number of abrasive particles, high water cut, corrosion activity of the environment, etc.);

– simplicity of unit structure and easy maintenance process.

However, high number of accidents in sucker rod-pumping units caused by presence of significant dynamic components, constantly changing external loads, susceptibility of a beam-balanced unit to unsuitable environmental environment, installation and maintenance defects, its operation beyond the designed life length lead to an increase in operating costs and a decrease in the profitability of the oil production process [4].

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It should be noted that one of the key factors that have a significant impact on the sucker rod-pumping unit failures is the equilibrium of the beam-balanced pumping unit, which determines the level of dynamic loads on the units of the machine and the value of specific energy inputs for the rise of the formation fluid. Currently, in the oil fields of Russia, the balancing of beam-balanced units is carried out, as a rule, by using current clamps that control the magnitude of the current in the stator windings of an asynchronous electric motor. Since normally the driving motors of the beam-balanced unit are under-loaded in the operating mode, the reactive power components predominate in the motor windings that are not related to the load, which results in a low efficiency of beam-balanced unit balancing according to the acting currents. According to the contracting organizations, which carry out the technical service of the sucker rod-pumping units, about 65 % of the existing beam-balanced units located in the Russian oil fields are incorrectly balanced [7, 10-11, 16].

Assessment of load of beam-balanced pumping units with asynchronous electric drive. The simplicity and reliability for automatic systems for monitoring the parameters of the operation of pumping units is an integral factor in view of the complicated conditions of equipment operation, price framework (competitiveness, profitability), mutual interaction of the sucker rod-pumping unit elements.

The analysis of the magnitude and nature of the changes in external loads determined by the measurement of the powers consumed by electric motors of the balanced beam pumping unit is one of the most promising methods of instrument control and assessment of the technical condition of the sucker rod-pumping units [7, 12, 14-15].

The employees of OJSC SIE «ROS» (Perm) developed and is producing software recording system «AKD-SK», which is designed for continuous monitoring of electrical parameters of a beam-balanced pumping unit (Fig. 1).

The software recording system «AKD-SK» include the following components:

1) a controller with an indicating light unit;
2) clip-on current transformers;
3) a magnetic type indicator.

The system is installed in the control station of the beam-balanced pumping unit, it has a connector RS 482 for connection to the operator network. There is an additional option which allows connecting the unit for wireless transmission of data from the controller to the network, to a laptop or tablet [5]. To power the system and register the instantaneous voltage values consumed by the drive motor of the

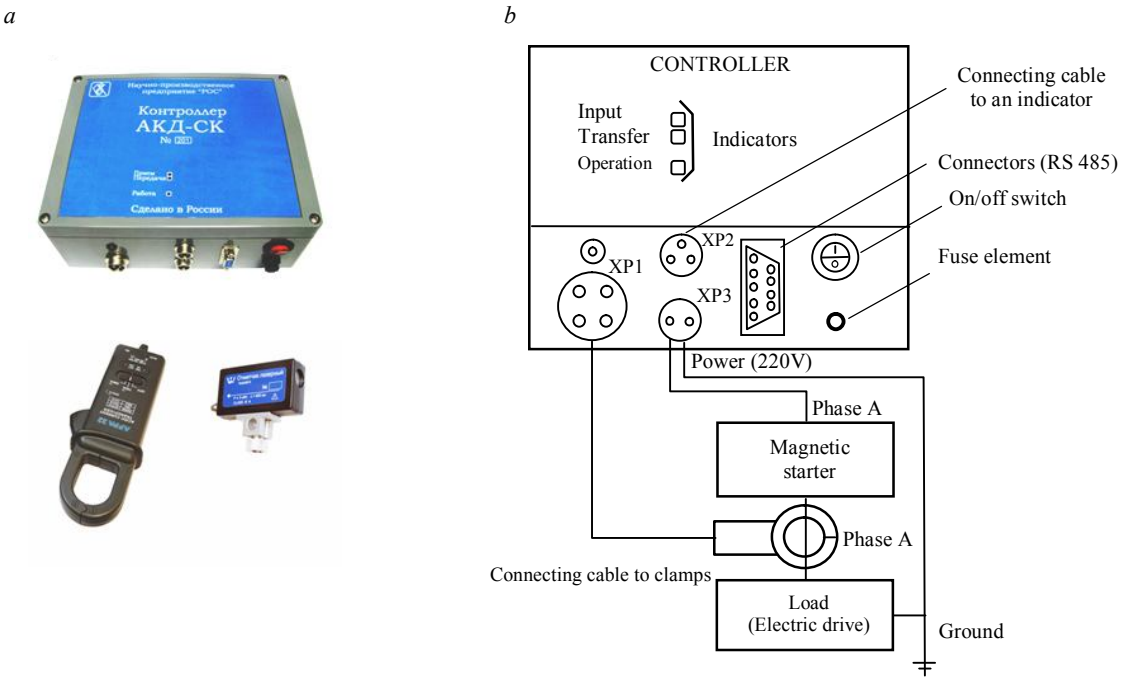


Fig.1. The «AKD-SK» system: *a* – external view; *b* – electrical diagram

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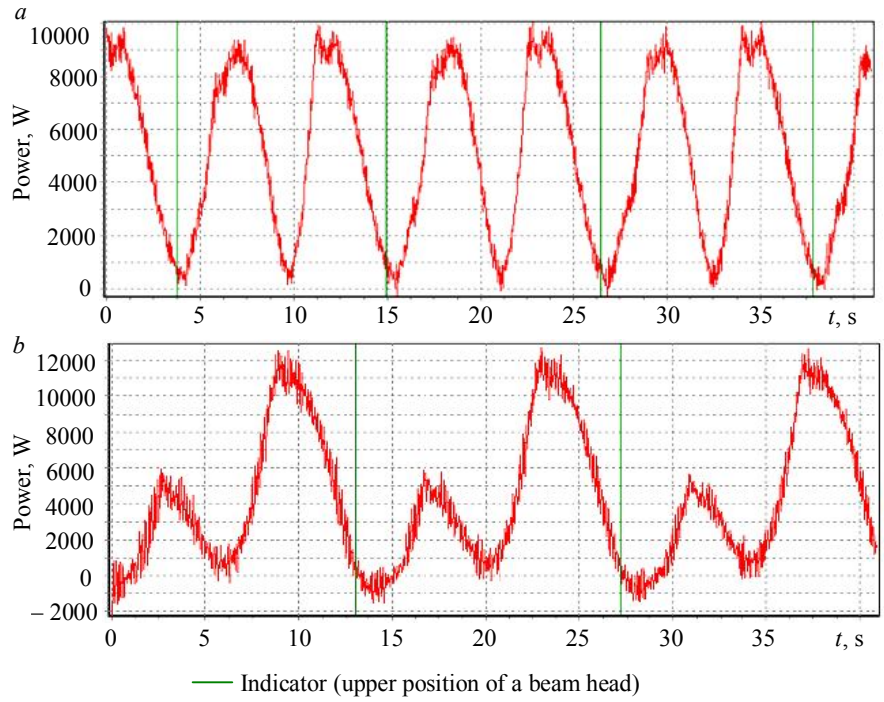


Fig.2. Watt-metrograms: *a* – fully balanced beam unit (good technical condition); *b* – unbalanced beam unit (small load)

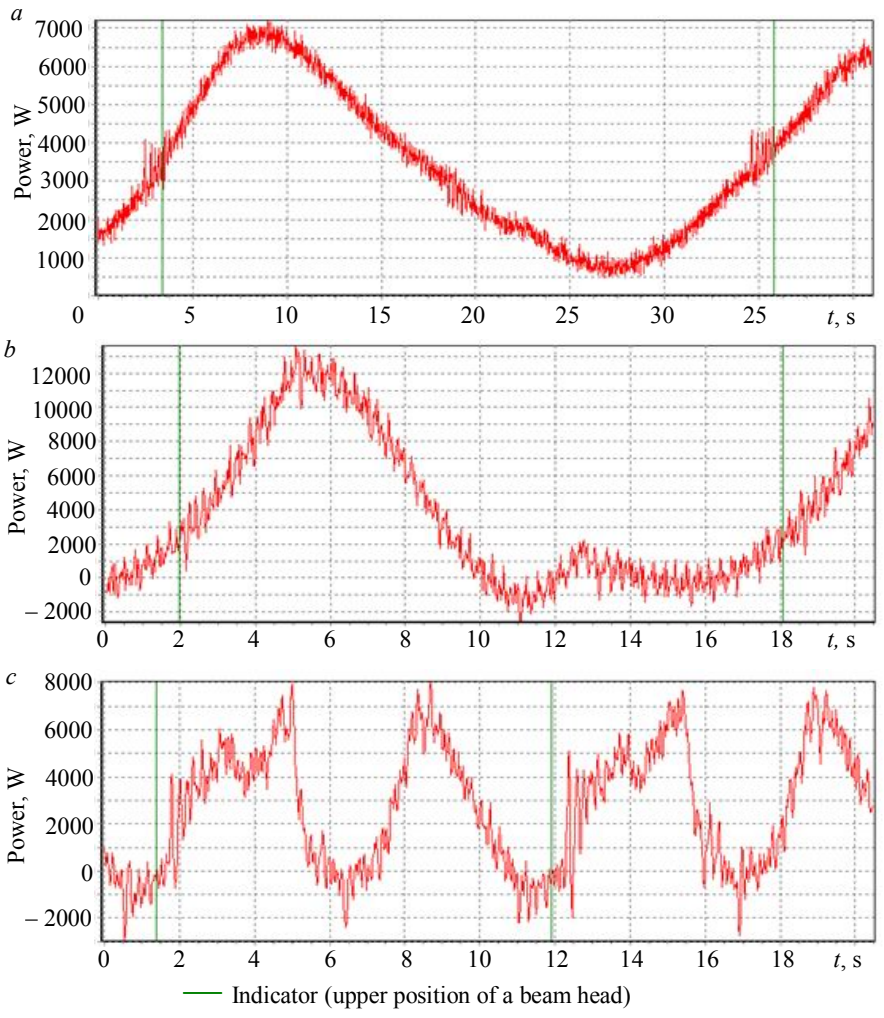


Fig.3. Diagnostic indicators of defects in rod-pumping units shown at watt-metrograms: *a* – parted rods; *b* – defect of a discharge valve; *c* – defect of an intake valve

beam-balanced pumping unit, the power cable of the controller is connected through the XP3 connector with one of the input phases (for example, phase A) of the magnetic starter and the grounding bar. The clip-on current transformers are placed on one of the phase conductors coming from the output of a magnetic starter, and are connected to the controller through a XP1 connector. The locking of the lower (upper) position of the head of the beam is carried out by using a magnetic type indicator that is mounted on the beam unit frame next to the output shaft of the reducer and connected to the controller by a connecting cable through the XP2 connector. At the same time, the magnet is mounted on the output shaft of the reducer in a place corresponding to the lower (upper) position of the head of the beam balance wheel [7].

The visualization and processing of watt-metrograms (Fig. 2) are carried out using specialized software installed on personal computers (and/or notebooks) of employees of engineering and technical services of the oil field [7].

The watt-metrogram of a fully balanced and serviceable beam unit (Fig.2, *a*) for each full stroke of the wellbore pumping rod has two half-periods with pronounced peaks corresponding to the horizontal positions of the crank. According to the current standards, the difference in the maximum power values consumed by the drive motor of a beam unit when lowering and raising the stem of the downhole pump must not exceed 10 % . The insufficient amount of counter-torque produced at the unbal-

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anced beam unit by crank loads when the column of the borehole pumping rods is lowered (Fig.2*b*) causes the drive motor to go into the generator mode of operation, and the stroke of the pump stem is accompanied by increased loads on the gearbox and engine of the beam unit. The consequence of these processes is an increase in the specific energy consumption for the rise of the reservoir fluid, high dynamics and the excess of the normative values of the loads on the beam unit elements [7].

The analysis of the obtained watt-metrograms allows to diagnose the most common defects of rod borehole pumps (Fig.3). The diagnostic sign of the break in the column of the sucker rod-pumping units is an increase in the peak values of the active power consumed by the engine when the balance head is lowered and the half-period of power increase on the watt-meter is absent when the balance is raised (Fig.3, *a*), which is caused by the absence of an external load created when the column of the formation fluid from the well is raised. Similarly, defects in the discharge valve of the submersible pump are manifested: a significant reduction in the power consumed by the engine when the piston is raised is due to leakage of most of the formation fluid through the faulty piston pressure valve back to the pump cylinder and, as a consequence, a significant reduction in the load at the suspension point of the column bars (Fig.3, *b*). The uneven load is buildup when the rod string is lowered, the increase in the dynamic components of the force effects on the sucker rod-pumping unit drive is a sign of a malfunction of the downhole pump intake valve (Fig.3, *c*) [7].

Assessment of load of beam-balanced pumping units with a permanent magnet motor. One of the ways to reduce the specific energy consumption and automation of the balancing beam units is the use of the electric motors (Fig.4) with excitation from permanent magnets. Since 2015, the OJSC «LUKOIL-PERM» oilfields are carrying out pilot-industrial operation of promising permanent magnetic motors developed by OOO «EPU-ITC» (Moscow).

Structurally, the permanent magnet motor (PMM), like any electric motor, consists of a stator and a rotor (Fig. 4, *a*). A stator – fixed part of the motor – contains windings, which serve to create a rotating electromagnetic field inside the engine. The PMM stator is mounted directly on the beam pumping unit gearbox, on the fastening of the bearing cover of the input shaft of the reducer. The rotor – the rotating part of the motor – is mounted on the input shaft of the beam pumping unit reducer and does not have its own bearing supports. The permanent magnets are mounted on the surface of the rotor, the number of which determines the number of poles of the PMM. Compared with asynchronous electric motors, PMMs are characterized by high efficiency and power factor, less thermal losses, masses and overall dimensions.

The operation of the sucker rod-pumping unit permanent magnet motors is carried out using control stations of the *VLT SALT* type, the operation principle of which is based on the implementa-

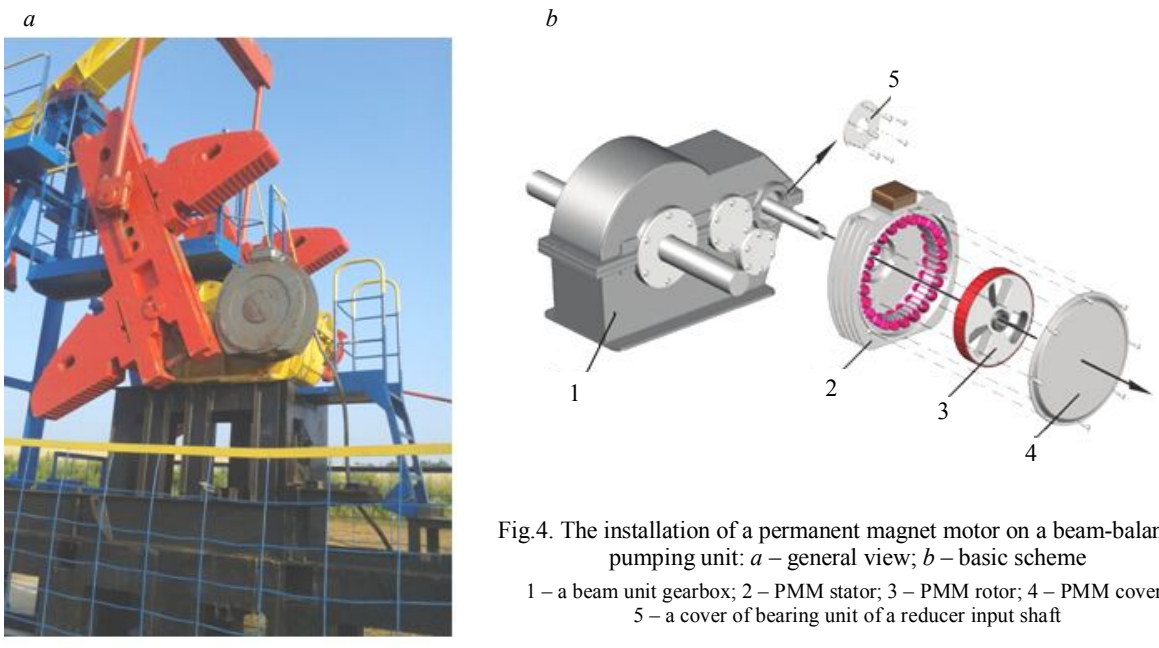


Fig.4. The installation of a permanent magnet motor on a beam-balanced pumping unit: *a* – general view; *b* – basic scheme

1 – a beam unit gearbox; 2 – PMM stator; 3 – PMM rotor; 4 – PMM cover; 5 – a cover of bearing unit of a reducer input shaft

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tion of software algorithms embedded in the memory of the process controller. The control station monitors the current state of the PMM, the magnitude and nature of the load on the motor shaft, forms the current-voltage and current values corresponding to the performed operation and current conditions, the phase between voltage and current, and the frequency of the supply voltage. This process during the work of the sucker rod-pumping unit is implemented continuously: from cycle to cycle, in accordance with the embedded algorithm, the technological controller adapts the task to the minimum energy consumption mode with the optimum capacity of the unit [1-3].

The mounting the PMM rotor on the reducer shaft eliminates the slippage and losses caused by the V-belt drive. The joint use of PMM with an intelligent control station provides the ability to adjust the parameters of the sucker rod-pumping unit within a wide range: the engine speed decreases at the extreme points of the rod stroke, the load limits are monitored and the speed of the movement is regulated in the beam lifting and lowering sections (four-period control is realized).

The comparative tests of balancing beam units equipped with a VDMM-SK-22V permanent magnet motor and an asynchronous 4AMI2002006U3/22/980 electric motor with a V-belt transmission were carried out at well N 1001 of the ZDDN-7 of OJSC «LUKOIL-PERM» Western deposit. The tests were carried out in two stages using the control station *Danfoss-SALT*, the beam balanced pumping unit SKDR-8-3 with the reducer CZNSH-450-40. At the first stage, the beam-balanced pumping unit was equipped with a permanent magnet motor, the control station was adjusted, and the specified technical parameters of the sucker rod-pumping unit were set. The methodology of the study included daily measurements of energy consumption and well production. At the second stage, the permanent magnet motor was dismantled and the V-belt pulleys and the asynchronous motor were installed on the beam unit. The test program was repeated in full volume with identical operating mode of the sucker rod-pumping unit [6].

Results of comparative tests of sucker rod-pumping unit drives (SKDR-8-3) at Western deposit (well N 1001)

Parameters	Motor type	
	4AMI200M6U3	VDPM-SK-22V
Motor power, kW	22	22
Motor shaft speed, rpm	975	450
Rod stroke length, m	3	3
Number of rod double strokes, min^{-1}	5.6	5.6
Measurement time, days	12	14
Specific energy consumption, $kW{\cdot}h/m^3$	5.4	4.7
Changes of specific energy consumption, %	100	87

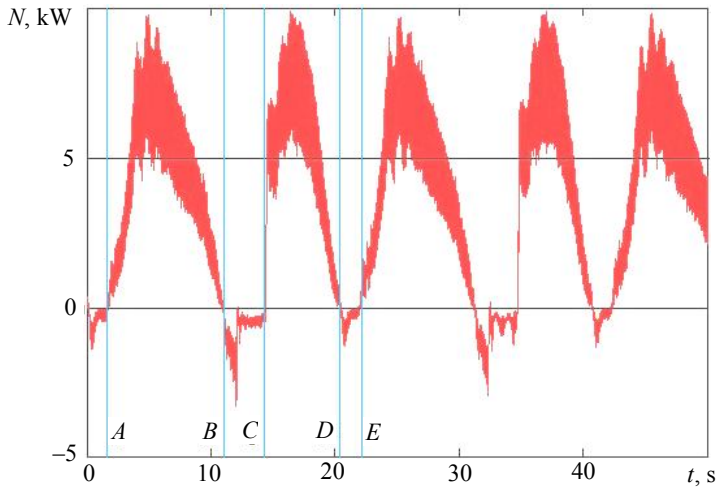


Fig.5. Diagram of power changes consumed by permanent magnet motor VDPM-SK-22V during beam unit operation: *AB* – lifting of a beam; *BC* and *DE* – transient processes at the end positions of the beam; *CD* – lowering of a beam

The test results showed a decrease in specific energy consumption with the use of PMM by 13 % (see table). The exclusion from the kinematic chain of beam unit the V-belt transmission and the use of intelligent control stations of the *VLT SALT* type provides the possibility of adjusting the parameters of the sucker rod-pumping unit operation in wide ranges with high speed and accuracy.

However, along with these advantages, one should also note the shortcomings revealed during the pilot-industrial tests of permanent magnet motors: significant cost of an intelligent control station of the *VLT SALT* type and PMM; complexity of setting up the control station; a small operating time of PMM for failure. The employees of engineering and service de-

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partments of the oil field suggested that the low reliability indicators of the tested PMM are due, first of all, to the selected parameters of the operating mode. However, the confirmation of this hypothesis required additional research.

The tests to assess the loading of units of beam-balanced pumping equipment with permanent magnet motors were carried out by the staff of the Department of Mining Electromechanics of the Perm National Research Polytechnic University using the portable software complex «VATUR», similar to the above described software recording system «AKD-SK» [13-15].

The analysis of the received power signals (Fig.5) shows that the implementation of the algorithm of four-period control of the PMM causes the occurrence of significant dynamic loads on the units of the beam-balanced pumping machine and in particular on the bearing supports of the reducer. Lifting of the beam is carried out at a reduced speed of rotation of the rotor of the engine in order to decraese peak loads and more complete filling of the well pump with a reservoir fluid (period *AB*, Fig.5). When the beam is lowered and the crank is raised, the rotor speed of the motor is increased by changing the supply voltage frequency of the *VLT SALT* control station (*CD* period, Fig.5).

Increasing the duration of the *AB* period and decreasing the *CD* in each cycle of the beam-balanced pumping unit operation period allows to reduce the specific energy consumption for the rise of the reservoir fluid, which increases the efficiency of the sucker rod-pumping unit. At the same time, the end positions of the beam are characterized by the transient processes (periods *BC* and *DE*) and the generator operating modes of the engine. In sections *BC* and *DE* (Fig. 5), the drive motor is the source of dynamic loads, which, due to the rigid fixing of the PMM rotor on the reducer shaft, primarily influence the bearing supports of the beam unit gearbox. The lack of its own bearings in the tested PMM causes a high probability of engine jamming when bearing operation is disrupted and radial beats appear on the drive shaft of the beam unit gear.

Conclusions. The constant registration of signals of active powers consumed by drive motors of sucker rod-pumping unit allows to obtain up-to-date and reliable information on the operational parameters of this pumping equipment and, based on the data obtained, to most effectively and reliably control the loading of the sucker rod-pumping units and to qualitatively perform the balancing of the beam unit. Due to this, the energy costs for lifting the reservoir fluid and dynamic loads on the sucker rod-pumping unit elements are reduced. The study of information on the magnitude and nature of the change in the loading of the drive motors of beam unit allows us to evaluate the technical state of the elements of the sucker rod-pumping unit. The results of the research presented in this article prove the prospects of developing means for monitoring the technical condition of equipment that evaluate the magnitude and nature of the change in power consumed by electric motors.

REFERENCES

1. Usachev O.I., Ginzburg M.Ya., Egnus A.E., Pavlenko V.I. Transmissionless power-efficient drive group of beam pumping unit. *Neftegazovaya vertikal'*. 2014. N 17-18, p. 100-103 (in Russian).

2. Ivanov S.L. Increase the resource of transmissions of mining machines based on the assessment of the energy load of their elements. Sankt-Peterburgskii gornyi institut. St. Petersburg, 1999, p. 92 (in Russian).

3. Barkov A.V., Barkova N.A., Borisov A.A., Fedorishchev V.V., Grishchenko D.V. The technique of diagnosing mechanisms with an electric drive according to the consumed current. NOU «Sevzapuchtsentr». St. Petersburg, 2012, p. 67 (in Russian).

4. Molchanov A.G. Machines and equipment for oil and gas production. Moscow: Izdatel'skii dom Al'yans, 2010, p. 588 (in Russian).

5. Passport «Stationary software-hardware system АКД-СК». NPP «ROS». Perm', 2015, p. 13 (in Russian).

6. Mazein I.I., Ustinov A.N., Tyaktev M.V., Rybin A.A., Shishlyannikov D.I., Tyaktev M.M. Results of pilot-industrial tests of prospective drives of sucker rod-pumping units. *Gornoe oborudovanie i elektromekhanika*. 2016. N 9, p. 8-14 (in Russian).

7. Sof'ina N.N., Shishlyannikov D.I., Kornilov K.A., Vagin E.O. Method for monitoring the parameters of operation and technical condition of sucker rod-pumping units. *Master's Journal*. 2016. N 1, p. 247-257 (in Russian).

8. Burkov P.V., Burkova S.P., Timofeev V.Y. Justifying a method of balancing crank-and-rod mechanism of mining roadheader. *Applied Mechanics and Materials*. 2014. Vol. 682, p.270-275. DOI: 10.4028/www.scientific.net/AMM.682.270.

9. Dong L., Han X., Hua L., Lan J., Zhuang W. Effects of the rotation speed ratio of double eccentricity bushings on rocking tool path in a cold rotary forging press. *Journal of Mechanical Science and Technology*. 2015. Vol. 29. Iss. 4, p.1619-1628. DOI: 10.1007/s12206-015-0333-5.

10. Gaivoronskiy I.N., Kostitsyn V.I., Savich A.D., Chernykh I.A., Shumilov A.V. Ways of improvement of reservoir completion efficiency. *Neftyanoe Khozyaystvo – Oil Industry*. 2016. Iss. 10, p.62-65.

11. Kostyukov V.N. Real-time condition monitoring of equipment. 7th International Conference on Condition Monitoring and Machinery Failure Prevention Technologies. 2010. Vol. 1, p. 239-246.

12. Kostyukov V.N., Tarasov E.V. Real-time condition monitoring of thermal power plants feed-pumps by rolling bearings supports vibration. *Journal of Physics*: *Conference Series*. 2012. Vol. 364. Iss. 1. Article number 012131. DOI: 10.1088/1742-6596/364/1/012131.

13. Kostyukov V.N., Kostyukov A.V. Real-Time monitoring of machinery operation hazards. *Neftyanoe Khozyaystvo – Oil Industry*. 2014. Iss. 9, p.46-49.

14. Kowalczyk A., Witkowski A.J. Groundwater recharge of carbonate aquifers of the Silesian-Cracow Triassic (southern Poland) under human impact. *Environmental Geology*. 2008. Vol. 55. Iss. 2, p.235-246. DOI: 10.1007/s00254-007-0999-9.

15. Shishlyannikov D.I., Chekmasov N.V., Trifanov M.G., Ivanov S.L., Zvonarev I.E. Substantiation of the rational method to control the operating and technical-condition parameters of a heading-and-winning machine for potash mines. *Journal of Machinery Manufacture and Reliability*. 2015. Vol. 3, p.283-287. DOI: 10.3103/S105261881503019X.

16. Shishlyannikov D.I., Vasilyeva M.A. Operational control and diagnostics of the equipment by the parameters of the electric drive power supply by the example of deep well pump units. MEACS2016, IOP Conference Series: Materials Science and Engineering. 2017. Vol. 177, p.12-16. DOI: 10.1088/1757-899X/177/1/012013.

Authors: **Dmitriy I. Shishlyannikov**, *Candidate of Engineering Sciences*, *Associate Professor*, *4varjag@mail.ru* (*Perm National Research Polytechnic University, Perm, Russia*), **Aleksandr A. Rybin**, *Doctor of Engineering Sciences*, *Professor*, *aarybin@pstu.ru* (*Perm National Research Polytechnic University, Perm, Russia*).

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