Operational control and diagnostics of the equipment by the parameters of the electric drive power supply by the example of deep well pump units

D I Shishlyannikov and M A Vasilyeva

1 Perm National Research Polytechnic University, 29, Komsomolsky Ave., Perm, 614990, Russia
2 Sankt-Petersburg Mining University, 2, 21-st Line, Vasilyevskiy Island, St Petersburg, 199106, Russia

E-mail: saturn.sun@mail.ru

Abstract. Currently, the vast majority of Russian oil wells use oil well pumping units (OPU), equipped with a mechanical drive – a balancing pumping unit. The significant lifetime of balancing pumping units used in oil fields of Russia amounts to full or close to full resource generation and to a high accident rate of the mechanical drive rod of OPU. Reduced material costs for operation and maintenance of OPU may be provided by the rejection of the system of preventive maintenance and service during the transition to the actual technical condition. The article analyzes the statistics of the most frequent crash balancing pumping units of OPU and their causes. The prospect of applying the method of instrument control parameters is proved, and the technical condition of the OPU is assessed based on the analysis of the magnitude and the nature of changes in load drive motors, determined by the recording of the instantaneous values of power consumption. The authors consider the construction and operation of the programmable controller ‘AKD-SK’ manufactured by JSC R&D company ‘ROS’ (Perm). Fundamentals of vattmetrogramm analysis of OPU drive motors are stated, and the character of displaying key defects of submersible pumps and balanced beam unit is described.

1. Introduction

For oil-producing enterprises engaged in well operation using deep well pumping units (DWPU), the tasks of enhancing the efficiency of using DWPU by means of reducing material costs for the maintenance of their working capacity, reducing the number of crashes and by the transition from a planned preventive repair system of pumping equipment to servicing according to the actual technical condition remain relevant.

Solution of these problems is possible through the development and widespread use of methods and tools of instrument control, implementing a continuous monitoring of DWPU operating parameters. They allow quantifying the loading drive and to monitor the intensity of the flow of the degradation processes in the DWPU subassemblies which are most subject to wear [1, 2].

Currently, in the Russian and CIS countries oil fields, DWPU with a mechanical drive – balancing beam pumping unit — are the most common. These units represent a conservative set of equipment, the construction of which has not been fundamentally changed over the last 40 years. The main advantages of DWPU with a mechanical drive can be related to long periods of operation, simplicity
of the construction and maintenance, as well as to the use of rod pumps at marginal wells under complicated geological conditions (high water content, significant content of abrasive, sulfur, paraffin reservoir fluid, etc.). However, significant dynamic components and variability of external loads, exposure of the beam-pumping unit (BPU) to the adverse effects of the atmosphere, installation and adjustment errors, improper maintenance and operation of the BPU beyond the normative periods stipulate a high accident rate of DWPU, which leads to an increase of operating costs and a reduction of profitability of an oil extraction process [3].

2. Materials and methods

According to data provided by the JSC ‘Lukoil-Perm’ company (Table 1), the most frequent emergency failures of BPU balancers of the DWPU include: destruction and withdrawal of the finger out of the crank (41%), depreciation and destruction of the low-speed shaft of the gearbox (20%), rapture of the connecting rod (17, %). Among the main reasons stipulating the occurrence of unexpected failures are metal fatigue, exceeding normative load, low level of service of DWPU.

| Emergency failure                                      | The proportion of the total number of failures, % |
|--------------------------------------------------------|--------------------------------------------------|
| Getaway of the crank from the gear box driven shaft    | 3                                                |
| The output pin from the crank                          | 8                                                |
| The destruction of the crank pin                       | 33                                               |
| Breakage of the balancer                              | 3                                                |
| Breakage of the traverse                              | 5                                                |
| Breakage of the connecting rod                         | 17                                               |
| The destruction of the traverse support                | 3                                                |
| Breakage of the head rocker                           | 8                                                |
| The destruction of the gear (low speed shaft breakage) | 17                                               |
| The destruction of the gearbox gears                   | 3                                                |

The most common causes of failure of the deep well pumps are the parted rods, defects of receiving and discharge valves, corrosion and abrasive damage of work surfaces.

It should be noted that one of the key factors that have a significant impact on the operating time of DWPU is the balanced state of BPU, determining the level of dynamic loads on the machine components and the amount of specific power inputs for the rise of the reservoir fluid. Today, the following methods are most commonly used for balancing mechanical BPU:

– weight balance – the oldest and simplest method, implemented by using a set of heavy plates, mounted on the rear end of the rocker BPU;

– rotor balancing – the loads in the form of counter-balances are placed on heavy cranks, the mass of which is also involved in the process of balancing of the equipment;

– combined, rotary-balancing counterbalance – the most effective, is used in most of the BPU domestic and foreign production.

The main purpose of balancing BPU devices is accumulation of potential energy when the rods move downwards and output of the energy when the rods move upwards. Supplied potential energy is converted into work, which, together with the work done by the drive motor, is spent on the movement of the suspension point of the column of rods upwards and lifting oily liquid from the well.

Currently, at oil fields of Russian, BPU balancing is generally performed using a current clamp, controlling the amount of current in the stator windings of the asynchronous motor. Because the drive motors are usually underused in the BPU operation, the motor windings are dominated by the reactive power components that are not related to the load, resulting in low efficiency of balancing the BPU under existing currents. According to the contracting organizations carrying out technical service of DWPU, about 65% of the existing BPU park are incorrectly balanced at Russian oil fields.
Difficult operating conditions of oilfield equipment, a multifactorial process of interaction of elements DWPU among themselves and with the external environment, as well as price restrictions (profitability, product competitiveness in the market conditions), necessitate a technically simple and reliable solutions in the design of automatic parameter control systems work and evaluation of technical state pumping systems. One of the most promising ways of instrument control and diagnostics of DWPU is to analyze the magnitude and the nature of changes in the external load, determined by measuring the instantaneous values of currents, voltages, and to calculate the power consumed by the motor of BPU [4-12].

3. Research and discussion

Employees of JSC R&D ‘ROS’ company (Perm) developed and commercially produced programmable controller ‘AKD-SK’, designed for continuous monitoring of machine-rocking electric parameters. The complex is used for registration wattmetergramm on energized equipment without prior disconnection that allows us to diagnose and monitor the balance of the BPU, and send the results to the operator of the oil field network.

The structure of the ‘AKD-SK’ equipment complex (Figure 1) includes a controller with light diodes to indicate, a clamp meter and a timer of a magnetic type. The complex is directly mounted in the control station of BPU, has the external output RS 482 connector (Figure 2) for connecting of an operator of the oil field to a network and the additional option of wireless data transfer from the controller to the network, laptop or tablet [13].

![Figure 1. The external view of the programmable controller ‘AKD-SK’.](image1)

![Figure 2. The structural scheme of the programmable controller ‘AKD-SK’.](image2)

For the power supply of the complex and registration of instantaneous voltage values consumed by the BPU engine drive, the power cable connecting the controller via connector XP3 is put on one of the input phases (e.g., phase A) of the magnetic actuator and the ground bus. The clip-on ammeters are set on one of the phase wires coming from the output of the magnetic contactor and connected to the controller via connector XP1. Fixing the lower (upper) position of the balance head of BPU is carried...
out by using a timer of the magnetic type, which is mounted on the frame of BPU near the output shaft of the gearbox and is connected to the controller via connecting cable connector XP2. At the same time on the gearbox output shaft, the magnet was mounted in a position corresponding to the lower (upper) position of the head of the balance of the SC. The obtained data are stored in the controller's volatile memory and are transmitted on request to the operator of a network of an oil field. Visualization and vattmetrogramm treatment (Figure 3) is carried out using the specialized software installed on personal computers (and / or notebooks) of the technical services staff of the oilfield.

![Vattmetrogramms of fully balanced BPU, good technical condition.](image1)

![Vattmetrogramms of unbalanced BPU (small load).](image2)

Vattmetrogramma of the fully balanced and serviceable BPU (Figure 3) for each full stroke of the downhole pump rod has two half-cycles with distinct peaks corresponding to the horizontal position of the crank. According to the established standards, the difference values of the maximum values of power consumed by the drive motor of the BPU when lowering and raising the rod well pump should not exceed 10%. An insufficient magnitude of the anti-moment generated by crank loads when lowering the rod string down of the hole pump during an unbalanced BPU (Figure 4) determines a transition of the drive motor in the generator mode of operation, and the working stroke of the pump shaft is accompanied by increased loads on the gearbox and the BPU engine. The consequence of these processes is an increase of the specific energy consumption during the rise of the formation fluid, high dynamics and exceeding the loads regulatory values in the BPU elements.

Analysis of vattmetrogramms allows us to predict the most common defects of deep well drilling pumps. Diagnostic features of breakage of the OPU rod string is an increase of the peak active power values consumed by the motor when lowering the head rocker (the rod string weight does not
compensate an anti-torque produced by the weights crank). At that, the half-period of the power increase is absent from the wattmetrogramme when the rocker is lifted, which is caused by the absence of an external load exerted when lifting the reservoir fluid column of the well. Similarly, the defects of the discharge valve of the submersible pump are shown. They are a substantial reduction in the power consumed by the motor when the piston rises due to leaking of a greater part of formation fluid through the faulty discharge piston valve back into the pump cylinder, and, as a consequence, a significant decrease in the load suspension point of the column bars. The unevenness of the load growth while lowering the rod string, an increase of dynamic components of a force on the drive of BPU indicate a malfunction of the valve of the receiving borehole pump.

Spectral analysis of the active power signal (Figure 3) obtained by the programmable controller ‘AKD-SK’ allows revealing frequency components from 0 to 30 Hz characterizing the kinematic chain fluctuations ‘borehole pump – pumping unit – gearbox – drive motor’. Defects in working units and mechanical gears of OPU determine the occurrence of variable loads, which causes the appearance of new spectral components. Periodic measurement values in the power spectrum, characterizing the specific defects in the drive motor and the mechanical transmission, allows carrying out the assessment of technical condition OPU in the most simplest mode and, if necessary, to carry out repairs exposure to prevent crashes.

![Spectra wattmetrogramm: a) in the presence of a defect motor pumping unit.](image)

Through spectral analysis of records of power consumption in induction motors (Figure 5), we can find defective electric parts of the rotor including the rotor winding breaks and short circuit between laminations; electrical parts of the stator including breakages and electrical asymmetry of power winding, short circuit between laminations; static and rotating eccentricities; bearing defects leading to fluctuations of the air gap forms. By the nature of changes in the spectrum of the signal of power consumption, we can diagnose fault gears, the fits of gears on the shaft, misalignment of driven shafts and their supports of rotation, defects of V-belt transmission (Figure 5).

The disadvantages of the method of estimation of the technical condition of DWPU relatively its power consumption refer to the difficulty of identifying a number of defects at the initial stage of development. First, these are the failures of rolling bearings, cranking, deterioration and destruction of crank pins. The origin and development of these defects are accompanied by a change in the diagnostic signals of the spectra in the higher frequency range [4, 6, 14, 15].

The increase in informativeness and accuracy of diagnosis is possible through the implementation of multi-parameter technical monitoring (acoustic emission, vibration diagnostics), implemented as an option controller ‘AKD-SK’. For example, setting wireless acoustic emission and/or vibration sensors on crank pins will prevent more than 40% of BPU sudden failures [12, 13].

4. Conclusion
Thus, the continuous recording of signals of active power consumed by drive motors SHSNU allows us to carry out the control over the operational loading of nodes of the pumping unit in the most
simple and reliable way, to qualitatively perform the balancing of BPU resulting in reduction of the specific energy consumption during the rise of the reservoir fluid and reduction of dynamic loads on OPU details. Analysis of relevant information on the magnitude and nature of the change of electric drives loading of BPU enables assessment of the technical condition, complete and residual life of OPU elements.

The results of studies, presented in the article, show the prospects of development tools for diagnosis, carrying out the control values and the changing of the nature of power consumed by the drive motors. The proposed technical solutions and methodological bases can also be successfully used for diagnostics and operational control of mining machines and technological equipment of mining enterprises.

References

[1] Sugak EV, Vasilenko NV, Nazarov G G and others 2001 The reliability of technical systems (Krasnoyarsk: Rasko)
[2] Molchanov A G 2014 Drilling and Oil 2 3-9
[3] Sungatullin A A, Norkina O A and Sadykova R R 2011 Proc. of the Int. Sci. and Techn. Conf. (Tjumen) vol 4 (Tjumen: TjumNGU) p 251-254
[4] Barkov A V, Barkova N A, Borisov A A 2012 Methods of diagnosing mechanisms by electric current consumption (Saint-Petersburg: Sevzapuchcentr)
[5] Sidorov V A, Kravchenko V M, Sedush V Ja and others 2003 Technical diagnosis of mechanical equipment (Doneck: Novyj mir)
[6] Asonov S A, Gabov V V, Ivanov S L, Trifanov M G, Chekmasov N V and Shishljannikov D I 2015 Bull. of Perm National Res. Polytechnic Univ. Geology. Oil and Gas and Mining (Perm: Perm National Research Polytechnic UniversityPress) p 62-71
[7] Sidel'nikov L G and Afanas'ev D O 2013 Bull. of Perm National Res. Polytechnic Univ. Geology. Oil and Gas and Mining (Perm: Perm National Research Polytechnic University Press) p 127-137
[8] Gur’ev P A and Nuss S V 2006 Bull. of Perm National Res. Polytechnic Univ. Geology. Oil and Gas and Mining (Perm: Perm National Research Polytechnic University Press) p 165-175
[9] Thorsen V and Dalva M 1997 University of Cambridge (Cambridge: University of CambridgePress) p 1-13
[10] Randy R S, Thomas G H, Kamrath F and Rodert G B 1995 IEEE Transactions on Industry Applications 4(6) 52-59
[11] William T T and Fenger M 2001 IEEE Industry Application Magazine 7 23-29
[12] Shishljannikov D I, Trifanov M G, Romanov V A, Ivanov S L and Asonov S A 2015 Mining Inform. and Analytical Bull. (Moscow: Moscow State mining University Press) p 227-233
[13] Passport ‘Stationary programmable controller ‘AKD-SK‘ (Perm: R&D company ‘ROS’)
[14] Petukhov V 2008 Electrical Eng. News 22(6) 33-37
[15] Kuptsov V V, Gorzunov A S and Sarvarov A S 2009 Bull. of South Ural State Univ. (Ekaterinburg: South Ural State University Press) p 123-129