Analysis of causes of failure of the electric centrifugal pump elements by the methods of automated diagnostics

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Abstract. The article discusses the issues of assessing the technical condition of electric centrifugal pumps (ECP) by the methods of automated diagnostics. The factors influencing the ECP and causes of failures of the electric centrifugal pump (ECP) and the submersible electric motor (SEM) are analyzed. The results of ECP failure identification using the measuring systems are presented. Recommendations on the operation of electric centrifugal pumps are provided.

1 Introduction
Currently, most oil wells are mechanical. Depending on the flow rate of wells under normal operating conditions, submersible rod pumps or electric centrifugal pumps are used [1].

The most common pumping units are electric centrifugal pump units (ECP). They account for almost 80% of all oil produced. The high-quality operation of the ECP determines the efficiency of oil production and productivity of the entire system. The operating conditions of the ECP are complex, they depend on the geological and technical characteristics of the bottomhole zone of the well, waterflooding systems, properties of the reservoir fluid. Under such conditions, the ECP begins to work unstably, the which causes additional mechanical losses and increases the energy cost.

Improving the reliability of pumping units is a technical and economic problem, since the reliability indicators can be increased only with minimal total resources spent on the development and operation of pumping units. Therefore, optimization of the ECP maintenance and repair is an urgent task.

In the fields of the north of Eastern Siberia, wells are equipped with electric centrifugal pumps. The regulated operation of such wells goes out of stability indicators as a result of wear or failures of technological equipment, elements of the well itself, as well as complicating phenomena: deposits of asphaltenes, resins, paraffins, sand, salts, corrosion products, mechanical impurities, premature watering of well products; changes in the operating conditions [2-4]. These phenomena decrease the oil well production rate, followed by downtime. Recognition and timely elimination of negative phenomena makes it possible to ensure high-quality and long-term operation of electric centrifugal pumps [5-6]. This is facilitated by the use of measuring systems for detecting failures of ECP equipment using automated diagnostics of operating parameters.
2 Materials and methods

When operating oil wells using electric centrifugal pumps, various types of problems arise every day [7].

The normal operation of oil wells is often disrupted due to wear or failures of surface and underground equipment, production casing and bottomhole, sand deposits, mechanical impurities, corrosion products, paraffin, salts, premature watering of products; changes in working conditions [8-10]. This is usually accompanied by a decrease or cessation of oil production and well shutdowns. The duration and quality of ECP operation depends on timely detection and effective elimination of these failures [11-12].

ECP failures occur due to
1) open circuit in the SEM supply circuit, at which the resistance is equal to "zero";
2) non-rotation of working bodies;
3) lack of fluid supply to the wellhead;
4) a decrease in the liquid supply at the wellhead due to the fault of submersible equipment below the permissible limits, at which the operation of the equipment is impractical in a long-term mode;

The most frequent failures occur for the first three reasons, which are the result of different operating conditions of submersible equipment, properties of well products, and well design. The impact of negative factors can lead to damage to various, most susceptible units and parts, and, accordingly, to various causes of equipment failures.

Probable reasons for ECP failure due to the lack of resistance:
1) breakdown of insulation and melting of the cable cores at the junction due to critical current loads, poor-quality production of splices, mechanical damage to the cable, insulation failure;
2) lack of tightness of the "cable-SEM" system and water protection.

The probable causes of ECP jamming are:
1) mechanical impurities in downhole products;
2) salt deposition;
3) high temperature in the ECP suspension area;
4) insufficient inflow.

ECP failures are classified into the following categories:
1) failure of a submersible electric motor: hydraulic protection, protector, electric motor (leakage, scrapping, dismemberment, mechanical damage to the shaft and bushings);
2) electrical cable failure: mechanical damage, breakdown, melting;
3) failure of the electric centrifugal pump: dismemberment, scrapping, mechanical damage to the stage, mechanical damage to bearings, leaks.

One of the main reasons for the wear of submersible pumping equipment is that the pumps are used at extremely low dynamic levels, causing an increased temperature effect on the ECP units. Frequent stops and starts of submersible pumping equipment associated with power outages, instability of voltage parameters also cause premature failures of the ECP. During stops, mechanical impurities in the pumped liquid are deposited on the working parts of the pump, which increases current loads, causes "overloads" and jamming of installations.

During the dismantling, a manufacturing defect was found: an insufficient amount of oil in the internal cavity of the engine, the oil had a burning smell, which also indicates excessively high engine temperatures. Increased pumping depth (at reservoir temperature 90-950C) leads to an increase in the temperature of the pumped liquid by 10-140C.

The quality of domestic submersible electric motors is similar to the imported ones. All the main elements of the reliable SEM, such as high-quality winding wire, fluoroplastic groove insulation tubes, are produced by almost all manufacturers. The main reason for the breakdown of the electric motor is the breakdown of the stator of the lower or upper bases. Therefore, it is necessary to achieve the maximum frequency of the grooves in the manufacture of the stator.

The main problem of the heat-resistant domestic cable is its low resource. It is economically inexpedient to replace a low-resource heat-resistant domestic cable with an imported one. It is
necessary to create high-quality insulation that can withstand temperatures up to 180 degrees and has an increased resource.

The situation is complicated by the fact that the failure of the ECP makes it necessary to carry out underground workover of wells. Underground repairs can last several days, the costs are often comparable to the cost of pumping equipment. With a rational organization of repair and maintenance, downtime losses can be minimized.

The duration and quality of ECP operation are affected by different factors - design characteristics and materials used in the ECP, physically heterogeneous processes (thermal, mechanical, geomagnetic, gas-dynamic, chemical) initiated by the technologies, geological properties of the reservoir. The combination of these factors leads to unequal lifetimes of equipment and its elements.

Accident statistics shows that the number of ECP accidents is approximately equal to the total number of installations. It means that every installation stops at least once a year. ECP failures can occur due to design flaws, poor-quality operation and repair, negative impacts of the extracted products.

The monitoring of the main parameters makes it possible to timely identify changes in the ECP operation and increase the efficiency of corrective measures aimed at increasing the pump resource.

The ECP is also affected by the wear of the pump parts in the presence of mechanical impurities, large operating time, wear of the textolite washers.

The wear due to the large operating time (more than 1250 days) and the ECP operation in the right zone are identical. The wear is monotonous and characterized by a decrease in the ECP performance within 2–4 months. The ECP wear is accompanied by:

1) a decrease in the strength of the supply current by 1–2% per month;
2) a decrease in the power consumption of the SEM by 2–3% per month;
3) a drop in the well production rate by 8-10% per month;
4) an increase in the specific energy consumption by 5-6% per month.

The ECP works without emergency stops. At the same time, the wear of the working bodies is the reason for the operation on the right side of the pressure characteristic of the ECP, which, during prolonged operation, can lead to overheating and failures of the submersible motor. With a decrease in the ECP flow rate below 0.7, it is necessary to replace worn-out equipment.

The analysis of the causes of failures of electric centrifugal pumps used at the Vankor field determined the following directions for improving the technical condition of electric centrifugal pumps:

- identification of problems, causes and factors affecting the level of ECP failures;
- identification of (un)reliable and (in)efficient equipment;
- identification of weak points in the ECP system, amendments to the technical requirements, use of improved structures and materials;
- improvement of the ECP application process, taking into account various well conditions;
- application of new ECP technologies and monitoring of their efficiency and reliability, identification of the best ones.

3 Results and discussion

In 2015, there were only 155 ECPs that did not fulfill the warranty period of 365 days. The structure of failures is shown in Figure 1.

The unit-by-node analysis of ECP premature failures showed that the most common failure units are ECP - 66 failures (42%); Tubing - 26 failures (17%); MBP (multiphase booster pump for pumping liquids) - 17 failures (11%); SEM - 17 failures (17%); hydroprotection - 15 failures (10%); extension cable - 8 failures (5%); cable line - 4 failures (3%); gas separator - 2 failures (1%). The causes associated with the wear of equipment and requiring replacement rank first and second in ECPs, tubings and MBPs. The causes associated with failures of the submersible motor (electrical part) rank third.

The structure of ECP failure causes is shown in Figure 2.
The cause “Clogging by mechanical impurities” ranks first (the Yak3-7 reservoir is a highly permeable reservoir with poorly cemented sandstone, prone to destruction) - 42 failures (27%) in 2015 (against the background of a drop in the bottomhole pressure, a non-decreasing dynamics of failures was observed).

The cause "Corrosion of tubing” ranks second - 21 failures (14%) in 2015.

The following causes rank third: "Gas impact" - 13 failures (8%); “Unsecured inflow” - 13 failures (8%); “Organizational reasons for EPU Service” - 13 failures (8%).

In 2015, an increase in the share of complicated corrosion and salt pool was observed due to a significant increase in water cut in the Vankor wells. With an increase in the water cut, failures caused by corrosion (a change in the type of emulsion from "water in oil" to "oil in water" increased to 8.

With an increase in the gas factor, unstable operation of wells was observed. It caused overheating of the working bodies of the ECP and its failure - 13 failures in 2015.

Organizational causes (13 failures) include failures in the complicated fund, due to a shift in the delivery time of materials and technical resources intended to protect the complicated fund.

The causes of ECP failures are shown in Figure 3. The main causes of premature failures are the influence of the following complicating factors: "Clogging with mechanical impurities" - 26 failures (39%); “Unsecured inflow” - 8 refusals (12%); "Salt deposits" - 7 failures (11%); "Gas impact” - 7 failures (11%).

The causes of SEM failures are shown in Figure 4. The main causes of premature failures are the following complicating factors: "Defect of EPUS repair" - 4 failures (23%) "Clogging with mechanical impurities" - 3 failures (18%); "Repair defect" - 3 failures (12%); ECP corrosion - 2 failures (12%).

![Figure 1. Distribution of failures of electric centrifugal pump elements](image-url)
1 - Impurities clogging, 2 - tubing corrosion, 3 - gas impact, 4 - org. causes, 5 - unsecured inflow, 6 - repair defect, 7 - ECP defect, 8 - well design,

Names of causes of ECP failures

**Figure 2.** Distribution of causes of failures electric centrifugal pump elements

1 - Impurities clogging, 2 - tubing corrosion, 3 - gas impact, 4 - org. causes, 5 - unsecured inflow, 6 - repair defect, 7 - ECP defect, 8 - well design,

Causes of ECP failures

**Figure 3.** Distribution of causes of failures electric centrifugal pump elements

1 - Impurities clogging, 2 - unsecured inflow, 3 - repair salt deposition, 4 - gas impact, 5 - org. causes, 6 - repair defect, 7 - well design, 8 - ECP corrosion, 9 - WSW causes, 10 - pillar leakiness, 11 - operation defect
Figure 4. Distribution of causes of submersible motor failures

- Organizational causes
- Impurities clogging
- Repair defect
- ECP corrosion
- Gas impact

Figure 5. Ratio of ECP complications to the operating fund

- Corrosion
- High gas factor
- High temperature
- ASPO
- Salts
- Mechanical impurities
- Fund without complications

Type of complications
Causes of ECP failures based on the results of inspections

Figure 6. Causes of ECP failures based on the results of inspections

ECP operation efficiency under the negative influence of complicating factors

Figure 7. ECP operation efficiency under the negative influence of complicating factors
When analyzing the data shown in Figures 5, 6, 7, 8, priority measures were developed to protect the ECP from complicating factors:

Factor 1 - Salt deposition:
1) Connection of wells with BDR (BTVN) and UDH for constant supply of salt inhibitors;
2) Connection of wells with BDR (BTVN) and UDKh for periodic supply of salt inhibitors;
3) Introduction of an inhibitor tube for constant dosing of scale inhibitors;
4) Regular dosing of salt inhibitors into the well annulus in an aqueous solution;
5) Regular flushing of HNO with a scaling solvent;

Factor 2 - Corrosion:
1) Introduction of an inhibitor tube for constant dosing of corrosion inhibitors;
2) Use of a tubing with a chromium content of 13%;
3) Connection of wells with BDR (BTVN) and UDKh for regular supply of corrosion inhibitors;
4) Connection of wells with BDR (BTVN) and UDH for constant supply of corrosion inhibitors;
5) Regular dosing of a corrosion inhibitor into the well annulus in an aqueous solution;

Factor 3 - Protection of the downhole equipment from ARPD:
- scraping of the tubing using mobile winches;

Factor 4 - Protection of the downhole equipment from mechanical impurities:
- placement in the filter layout.

4 Conclusion
The data show that the distribution of failures of the electric centrifugal pumps is not pronounced due to a variety of operating conditions. The use of new equipment and technologies cannot reduce the number of failures. Therefore, to maintain oil wells in a working condition by increasing the mean time between failures it is necessary to change the general strategy of well servicing. The preventive maintenance and repair systems based on the automated diagnostics of parameters and measuring systems, replacement of unit elements, adjustment of parameters and elimination of identified malfunctions can prevent ground equipment failures in production wells. Planned implementation of preventive measures will stabilize the equipment operation and increase equipment reliability and durability.
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