Predicting the reliability of auxiliary equipment of heat sources

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Abstract. Service equipment of the heat sources taken by supervision consisted of centrifugal water pumps, blast air fans and exhausters. Robust and fail safe operation of the heat sources is impossible without the effective operation of this service equipment. Malfunctions of the service equipment result in disruption of heat supply, losses and emergencies. Consequently, to provide a robust operation of the equipment there were found the impending failure, classified and described. The main type of the electric engines used for the electric drive of the working organs of the service equipment are asynchronous electric drives with a short-circuited rotor which is mostly exposed to the external influence. In this work there are collected and analyzed reasons of fault inception of the service equipment as well as methods to define the complex parameter of technical state is developed and its functional dependence on failure interval is set. The acquired data may be used to define the readiness of the equipment for operation to the coming period as well as plan its maintenance operation and overhaul.

1. Introduction

Boiler houses are the main sources of heat supply, which robust operation leads to normal functioning of the life support systems. The main service equipment of the boiler houses are centrifugal district heating pump and boost water pumps, blast air fans and exhausters [1]. Failures of this equipment result in failings of heat supply system, emergencies and material losses. Robust and fail-safe operation of the service equipment is impossible without the effective operation of the boiler houses, consequently investigation into the causes of failures of the given equipment and revealing the reserves of reliability enhancement is an actual problem.

The works of many authors are devoted to analyses of reliability enhancement of the service equipment [2-7]. In the course of analyses of literature sources it is set out that the analyses of operational reliability are limited by development of diagnostics methods and tests of service equipment. The developed methods mainly qualitatively measure the technical state of separate aggregates and joints that do not allow to measure the state of the equipment as a whole. [8-10]. The existing quantitative methods of readiness assessment of the aggregates are based mainly in definition of the complex values of readiness. The given parameters practically are defined on the bases of statistical data, time failure,
number of failures and their intensity that do not allow to forecast the operation of the equipment before the commence of operation and only after a definite operation time. [11-14].

The purpose of the given work is enhancement of reliability of operation of the service equipment by means of qualitative assessment of its technical state and forecast of operation for the coming period of operation. For that there were systemized the failures and the causes of their occurrence were analyzed [15-17]; theoretically well-grounded definition on complex value of the level of technical state [18]; based on the parameters of the technical state of the aggregate and its separate parts the methods of defining the level of the technical state was developed and its interrelation with complex parameters of robustness was specified.

2. Materials and methods
For experimental explorations there were chosen centrifugal water pumps which are a construction including the pump and asynchronous motor with short-circuited rotor. Performance efficiency of the aggregate mostly depend on the technical state of its separate joints as well as the parameters of its operation. Based on the that there were defined the factors which characterize the condition of the joints and there was created the model of formation of the complex parameter of the technical state. The experimental observations were conducted in the boiler houses of CJSC Baikalenergo since 2015 till 2018, more than two hundred units of the equipment were taken.

In figure1 there is depicted a percentage distribution of the occurred failures of the analyzed service equipment in the boiler houses.

![Figure 1. Auxiliary equipment fault diagram.](image)

Having analyzed the obtained data there was mentioned a large amount of emergency shutdowns of line rotor pumps, mechanical failures are more frequent than electric ones. It is connected mainly with a low robustness of mechanical part of the water rotor pump. While analyzing the work of blast air fans and exhaustors there is observed a reversed trend – pumping motors break down more frequently than the mechanical part of the blower that is the result of the negative influence of high temperature and impurity of air. Failures of asynchronous motor with short-circuited rotor mainly occurred due to the following causes: poor cooling, incorrect choice of the electric motor (current overload), open-phase operating conditions (missing phase), catching of the rotor, decreased resistance to insulation, environment conditions of operation (wetness, presence of aggressive media). Among the listed data the main emergency mode of electric rotors it is a loss of phase.

Having analyzed the failures of the service equipment of the boiler houses one may say about its low reliability. The failures occur not only because of the low quality of the equipment but also its incorrect choice and operation. Beside the equipment which is out of operation is not repaired and tested qualitatively that result in more frequent breakage.

Failures are a casual event, to prevent them the control of technical; state during the entire period of operation is required, especially before its commence. With faultiness and failures of separate elements at hand the majority of aggregates continue to function, i.e. continue to be functionally operative.
Qualitative assessment of the technical state of the aggregate which allow to define the degree of its functional operation is of a particular interest for the maintenance stuff [19-21]. This condition is mostly adhered to the methods of assessment of technical state on the complex parameter given in the work [18]. Consequently there appears the necessity of development of such a method of qualitative assessment of the technical condition of the aggregate which would allow without big losses of time and work to assess its readiness to functioning.

We suggest using as an assessment parameter "level of technical state" \((U_o)\). The method of definition of the general level of technical state by complex parameter was developed in conformity with a centrifugal water pump. The centrifugal water pump maybe considered as a system which consists of aggregates, mounting assemblies \(H=[A_1, A_2, ... A_n] \) (generalizing factors), which consist of assembly units, details, etc. \((\text{defining factors}) \) \(A_j=[S_1, S_2, ... S_m] \). Technological state of the defining factor is characterized with diagnostic parameters \(T_i=[d_1, d_2, ... d_n] \). As a whole the technical state of the generalizing factor is defined by the parameters of the states of the defining factors which consist it \(K_j=[z_1, z_2, ... z_m] \), on the basis thereof the complex parameter of the technical state of the pump is defined by summary assessment of the states of generalizing factors \(K_{pts}=[K_1, K_2, ... K_n] \). As a whole the qualitative parameter of the technical state maybe present as a combined function of technical states, elements included into this i.e. superposition of the type:

\[
K_{pts} = \psi (\phi (x)) \tag{1}.
\]

Application of this function as such for complex machines is not correct, because each factor has a different ponderosity (significance) in the machine. Consequently it is relevant to use the coefficient of the ponderosity, factor by the set criteria in dependence on the set characteristic.

On the basis of the observations of the operation of joints and aggregates of the pump, we defined three levels of the generalizing factors which are characterized by the state of the assembly units included into it, joints, aggregates and regulating parameters i.e. defining factors. We outlined the following generalizing and defining factors: parameter of the technical state of the pump (main body, framework, bearing, stuffing box, impeller, pump shaft); parameter of the technical state of the asynchronous engine (wrapping, body, frame, air blower, motor shaft); parameter of the technical state of box stuffing (half coupling, claws, plugs, coupling keys).

Definition of the complex parameter of the technical state of centrifugal pump commences with assessment of parameters of the defining factors, which definition is conducted in three stages: control of the pump part of the main assembly units is conducted visually; control of the electric part of the asynchronous rotor by the value of deviations of the parameters of dynamic parameters of the drive of the integral parts from nominal which switching on idling, control of insulation resistance, visual observation of the bearings and control of the compound parts of coupling connection, correctness of mounting of joints and aggregates, reliability of their fixing is checked. Then on the basis of the given assessments a qualitative assessment of the generalizing factors is defined. In the third stage as a whole the parameter of the technical state of the pump is assessed with consideration of the significance of the generalizing factors.

The basis of the experimental check of academic suppositions is a static method of the tests with the usage of element-by-element observations of functioning of centrifugal pumps.

3. Results of the research, their discussion
To confirm the academic suppositions, for observation there were taken pump aggregates, each of which was defined the level of technical state \(U_o\) for the beginning of the heating period. In table 1 there given the results of definition \(U_{oc}\) and mean time to failure.

| Pump brand | \(U_{mc}\) | \(t, \text{h}\) |
|------------|------------|------------|
|            |            |            |

Table 1. The level of technical condition and operating time of pumping units before failure.
By the received data taken during researches there were constructed different functional dependencies $U_{ts}$ from the parameters of reliability. In figure 2 there is given a dependence of the mean time to failure $T$, from the level of the technical state $U_{ts}$.

![Graph showing the relationship between Time to Failure and Level of Technical Condition](image)

**Figure 2.** Dependence of the operating time for failure of the centrifugal pump on the level of its technical condition.

As seen from the graph the given dependence is described by linear equation $T = 11269U_{ts} - 5408.5$ with high level of authenticity of approximation. With the growth of the level of technical state of the aggregate the mean time to failure is increased. The high coefficient of correlation confirms that this function may be used to forecast the operation time of the centrifugal pump for the coming period of operation.

4. **Conclusion**

To decrease the number of failures in operation of the service equipment it is necessary to organize the effective system of operation which considers the parameters of reliability of the equipment and results of check up its technical condition.

Apply diagnostics of the service equipment by the complex value of the technical state. The assessment shall be run either in the beginning of operation or after conduction of technical maintenance and repair.

The developed method of definition of the overall complex value of the technical state of centrifugal pump allows to qualitatively define the degree of its readiness for operation, check the quality of repair or technical maintenance and forecast its reliability before the heating period.
The obtained data in the course of assessment of the technical state may be used to forecast the operation of the service equipment for the coming period as well as to plan technical maintenance and repair.

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