Analysis of the safety of pumping units of pumping stations of machine water lifting in the function of reliability indicators

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Abstract. The article presents ways of analyzing the safety of pumping units of pumping stations of machine water lifting in the function of reliability indicators, taking into account the complexity of analyzing the safety of pumping stations of machine water lifting and presenting the pumping unit of a pumping station as a "system", as well as taking into account the need to attract information about their functional scheme, information about the reliability indicators of the elements included in these schemes, information about the adopted system of maintenance and repair, as well as the criteria for the failure of such systems, structural schemes for calculating the reliability of the pumping unit have been developed. The developed structural scheme for calculating the reliability of a pumping unit is presented, consisting of an electric motor, a pump, a power supply network, a control device, a converter, a machine exciter or a semiconductor excitation system, a winding, active steel, an excitation winding, a collector-brush apparatus, a bearing, guide bearings, an oil cooler, an air cooler of an electric motor, a working ring, guide bearings, system lubrication of pump bearings. Structural diagrams are also given for four variants of the design layout of pumping units: each pumping unit supplies water to its pipeline; several pumping units operate in one common pressure pipeline; the main and backup pumping units are connected in series; pumping units are connected to a common pressure pipeline in series-parallel. Based on these structural schemes, formulas for determining the probability of trouble-free operation of the pumping unit and pumping units, considering their structural layout, are compiled. The article assumes that the uptime of the synchronous motor of the pumping unit is distributed exponentially, and the law of the repair time distribution corresponds to the gamma distribution.

1 Introduction

According to [1], when conducting a probabilistic safety analysis (PSA), when information about individual processes and phenomena is missing or incomplete, the risk calculation is accompanied by a high degree of uncertainty. In this case, carrying out the PSA in full may

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be difficult. Then only qualitative and quantitative analyses of the reliability of the object are performed.

The pumping plant (PP) of a pumping station (PS) can be represented as a "system". To calculate the reliability of this system, it is necessary to involve information about their functional scheme, information about the reliability indicators of the elements included in these schemes, information about the adopted system of maintenance and repair, as well as about the failure criteria of such systems. In this regard, we have developed structural schemes for calculating reliability on PP (Fig. 1 a, b, c).

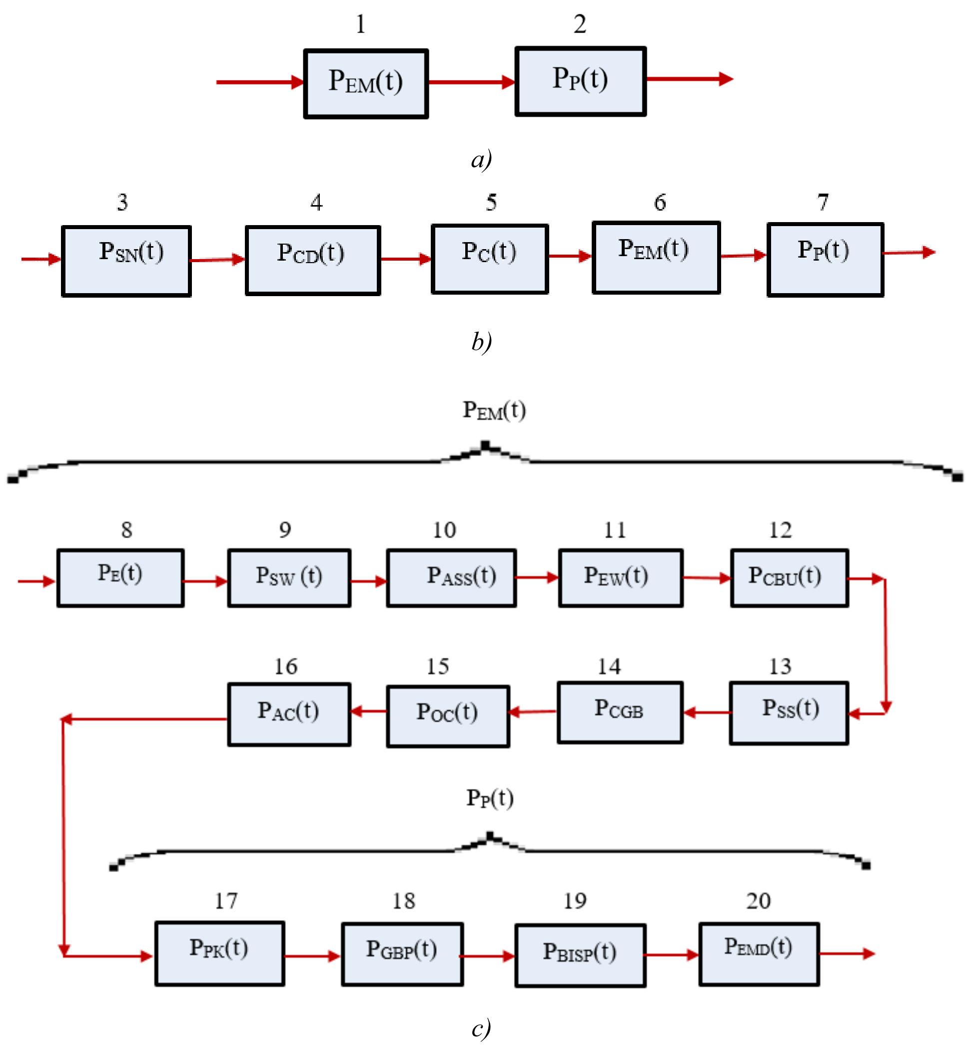


Fig.1. Block diagram of reliability calculation PU: 1, 6 are electric motor; 2, 7 are pump; 3 is supply network; 4 is control device; 5 is converter; 8 is machine exciter or semiconductor excitation system EM; 9 is stator winding EM; 10 is active steel stator EM; 11 is excitation winding EM; 12 is collector-EM brush unit; 13 is EM stator support; 14 is EM stator guide bearings; 15 is EM oil cooler; 16 is EM air cooler; 17 is impeller P; 18 is guide bearings P; 19 is bearing lubrication system P; 20 is electromechanical drive (electric drive) for turning the blades of the impeller P.

Let's consider a structural scheme for calculating the reliability of a pumping unit (PU). The block diagram of a pump unit with an adjustable electric drive (PU AED) can be represented by a sequential connection of elements - a supply network (SN), a control device (CD), a pre–educator (P), an electric motor (ED), a pump (P) (Fig.1, b). And the supply network includes a start-up control device (SCD) and soft-start devices or a frequency converter (the latter are not shown in Fig. 1, b). At the same time, the EM elements are divided into nodes: a semiconductor excitation system or a machine exciter, a stator winding; active stator steel; excitation winding; collector-brush apparatus; stator support; stator guide bearings; oil cooler; air cooler. The pump elements are divided into components: impeller, guide bearings, bearing lubrication system, and electromechanical drive (electric drive) for turning the impeller blades (Fig. 1 c).

2 Methods

When calculating the reliability of technical systems, a quantitative assessment of the probability of trouble-free operation P (t) is usually determined for a given period (tz). To calculate the probability of trouble-free operation when sequentially connecting elements, assemblies, and parts in the reliability theory, we use the probability multiplication theorem. Failure of any of the elements causes failure of everything PU. Reliability PU at the time of $P_{PU}(t)$ is defined as the product of the probabilities of failure-free operation of all sequentially connected elements and nodes according to the formula (Fig. 1 a) [2-26]:

$$P_{PU}(t) = P_{EM}(t) \cdot P_P(t). \quad (1)$$

The probability formula for calculating uptime on the PU AED compiled based on the block diagram (Fig.1, b) has the form:

$$P_{PU}^{AED} = P_{CD}(t) \cdot P_C(t) \cdot P_{EM}(t) \cdot P_P(t) \quad (2)$$

where is probability of failure-free operation of the elements:
$P_{CD}(t)$ is control device (CD);
$P_C(t)$ is converter (C).
At the same time, separately for each element, the probability of failure-free operation of ED is PU function of the probability of failure-free operation of their nodes:

$$P_{EM}(t) = P_E(t) \cdot P_{SW}(t) \cdot P_{ASS}(t) \cdot P_{EW}(t) \cdot P_{CBU}(t) \cdot P_{SS}(t) \cdot P_{SGB}(t) \cdot P_{OC}(t) \cdot P_{AC}(t)$$
$$P_P(t) = P_I(t) \cdot P_{GBU}(t) \cdot P_{BLS}(t) \cdot P_{EM}(t);$$

where probability of failure-free operation of nodes:
$P_{EM}(t)$ is electric motor;
$P_P(t)$ is of the pump;
$P_E(t)$ is a machine exciter or semiconductor excitation system of EM;
$P_{SW}(t)$ is EM stator windings;
$P_{ASS}(t)$ is active steel of the EM stator;
$P_{EW}(t)$ is EM excitation windings;
$P_{CBU}(t)$ is collector-brush apparatus EM;
$R_{SS}(t)$ is EM stator support;
$P_{SGB}(t)$ is guide bearings of the stator EM;
$P_{OC}(t)$ is oil cooler EM;
$P_{AC}(t)$ is air cooler EM;
$P_I(t)$ is impeller P;
$P_{GB}(t)$ is guide bearings P;
$P_{BLS}(t)$ is bearing lubrication systems P;

$P_{EMD}(t)$ is electromechanical drive (electric drive) of the rotation of the blades of the working wheel P.

As it is known [2], in existing pumping stations of machine water lifting, the well is structurally constructed in various variants depending on the required flow values, pressure, geometric parameters of the pressure pipeline, impellers, etc.

There are 4 variants of the constructive layout PP:

1) each PU pump supplies water to its individual pipeline, i.e., the number of pressure pipelines equals the number of pumps. For example, such an arrangement takes place at the pumping stations of the Karshi Main Canal (KMC);

2) several PU works in one common pressure pipeline. Such a connection was carried out on the NS "Hamza-1" and "Hamza-2" of the Amu-Bukhara Machine Channel. Ten pumping units are combined into two pressure pipelines at the "Hamza -2" NS;

3) the main and backup PU are connected in series;

4) PU connected to a common pressure pipeline in series-parallel.

To calculate the reliability of the PP, a block diagram of reliability is compiled for each option, depending PU the type of connection. Figure 2 shows a block diagram for calculating the reliability of the first option. Here, at one pumping station, all pumping units can be made up of the same type of electric motors and pumps or different types.

In the first case, all operational (experimental) data are entered into one table, and the calculation is carried out in the usual manner. In the second case, pumping units with the same type of EM and pumps are grouped, and their operational (experimental) data are entered into tables compiled separately for each type of pump and EM. Then the calculation is carried out for each corresponding group. In this case, the formula probability of trouble-free operation is WELL determined by the formula:

$$P_{PP}(t) = P_{ED}(t) \cdot P_P(t) \cdot P_P^I(t) = P_{PU}(t) \cdot P_P^I(t) \quad (3)$$

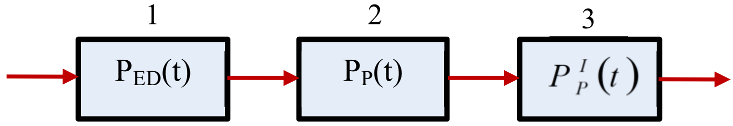
When the probability of failure-free operation of an individual pipeline $P_P^I(t)$ is equal to one, then expression (3) will take the form

$$P_{PP}(t) = P_{PU}(t) \quad (4)$$

The second option, Fig. 2, b shows a block diagram where the pumping units are connected in N parallel branches. In the beginning, the probability of failure-free operation of each pumping unit is determined. In this case, the formula for the resulting probability of no-failure operation of the PP:

$$P_{PP}(t) = \{1 - \prod_{i=1}^{N} \cdot [1 - P_{PUi}(t)]\} P_P^{GEN}(t) \quad (5)$$

Where $P_{PPi}(t)$ is probability of non-failure operation of the i-th parallel branch.



a)

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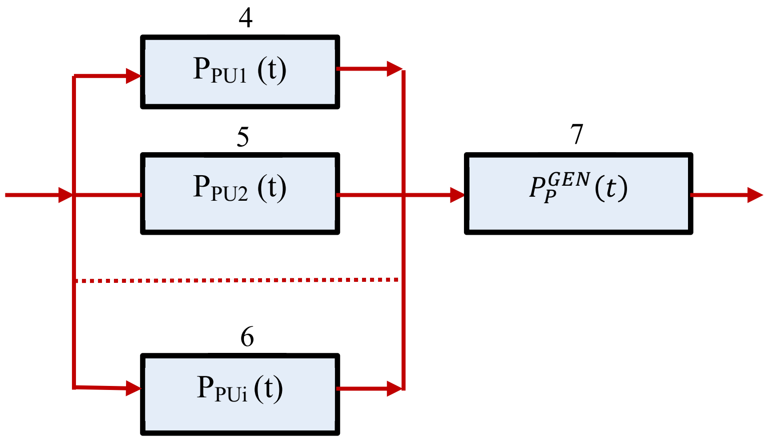
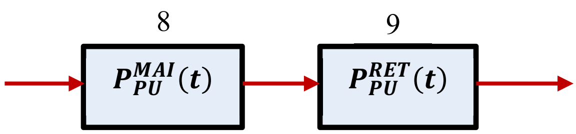
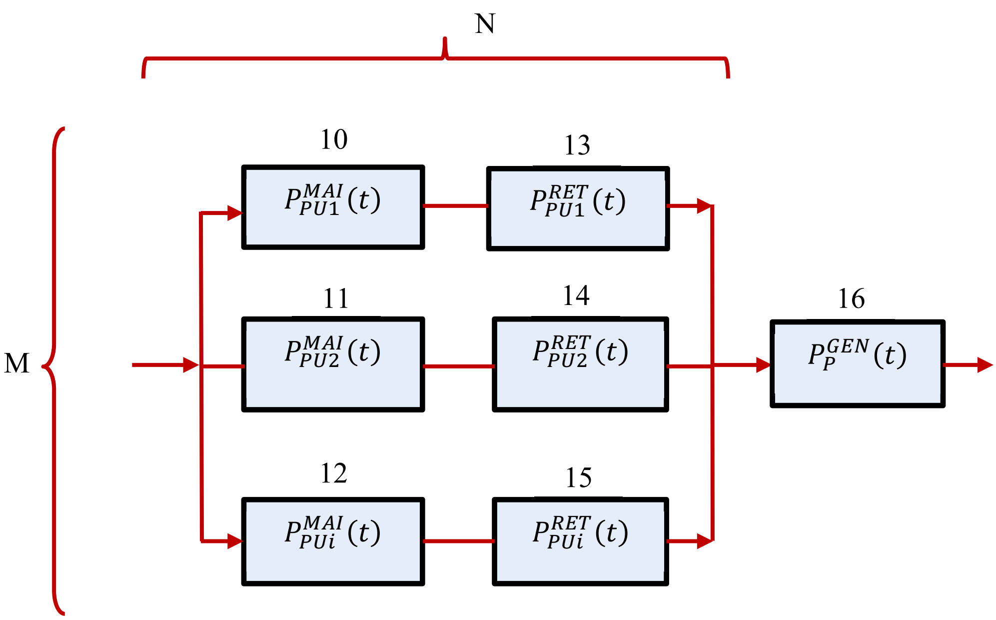


b)



c)



g)

Fig.2. Structural diagram of reliability of 4 variants of the design layout of pumping units: 1 is electric motor; 2 is pump; 3 is individual pipeline; 4, 5, 6 are pumping units; 7, 16 are common pipeline; 8, 10, 11, 12 are main pumping units; 9, 13, 14, 15 are retaining pumping units.

The block diagram of the reliability of the third option is presented in the form of a serial connection of pumping units (Fig.2, c). In this case, the formula of the resulting probability of uptime is PP:

$$P_{PU}(t) = P_{PU1}(t) \cdot P_{PU2}(t) = \prod_{i=1}^{N} P_{PUi}(t) \qquad (6)$$

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The structural scheme of reliability of the fourth option is presented in the form of a system consisting of M parallel chains of N blocks of pumping units in each (Fig. 2, d). In this case, the formula of the resulting probability of failure-free PP:

$$P_{PP}(t) = \{1 - [1 - \mathrm{P_{PU1}(t)} \cdot \mathrm{P_{PU2}(t)}] \cdot [1 - \mathrm{P_{PU3}(t)} \cdot \mathrm{P_{PU4}(t)}]\} \cdot \mathrm{P_P^{GEN}}(t) = \\ = \left\{1 - \prod_{i=1}^{N} \cdot \left[1 - \mathrm{P_{PUi}(t)} \cdot \mathrm{P_{PUj}(t)}\right]\right\} \cdot \mathrm{P_P^{GEN}(t)} \quad (7)$$

In the case when the probability of failure-free operation of all PU is the same and equal, then the formula (7) has the form:

$$P_{PP}(t) = \{1 - [1 - P_{PU}^{N}(t)]^{M}\} \cdot P_{P}^{GEN}(t) \quad (8)$$

The compiled structural schemes for calculating reliability allow us to analyze the PP's reliability, which consists of calculating the reliability indicators of the elements included in the emergency sequence. For elements that can be operated continuously during a given operating time t, the probability of trouble-free operation P(t) for a given operating time t is taken as the main calculation indicator. For elements that must be in standby mode with possible interruptions for maintenance and repair, the static readiness coefficient K_G is taken as the main calculation indicator.

An important aspect of calculating the reliability of PP elements is establishing criteria for their failures. When determining the criteria for failure of the PP, the description of the element, drawings, and other design documentation should be used.

The process of occurrence of failure moments is described by the corresponding probability laws, the main of which are considered in the course of "Reliability Theory". We have established that the uptime of the synchronous motor (SD) is distributed exponentially, and the law of the repair time distribution corresponds to the gamma distribution.

The failure rate of PP pump elements can be determined using special reference books, information in reliability databases, or design documentation for components.

Accounting for the specific operating conditions of the PP (temperature, humidity, vibration, and other influences) is carried out by introducing correction coefficients.

3 Conclusions

1. As a result of the investigation, it was established that during the PSA, when information about individual processes and phenomena is missing or incomplete, the risk distribution is accompanied by a high degree of uncertainty. In this case, carrying out the PSA in full may be difficult. Then only qualitative and quantitative analyses of the reliability of the object are performed.

2. The old PP pumping station is represented as a "system". To calculate the reliability of this system, it is necessary to involve information about their functional scheme, the reliability indicators of the elements included in these schemes, information about the adopted system of maintenance and repair, and the criteria for failure of such systems. In this regard, structural schemes for calculating reliability PU and four variants of the structural layout of the PP have been developed, and formulas for determining the probability of trouble-free operation PU and PP have been derived based on them, taking into account their constructive layout.

3. In the article, taking into account operational data, it is assumed that the uptime of the synchronous motor of the pumping unit is distributed exponentially, and the law of the repair time distribution corresponds to the gamma distribution.

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4. The developed structural schemes for calculating reliability will be useful in analyzing the safety PP of pumping stations, forecasting, studying possible reliability for various operating conditions and various thermal, mechanical, and electrical loads, and analyzing failures of applied elements.

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