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Dynamics of flooding of submersible pump stations and identification models for their automatic protection

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ABSTRACT

Deep-seated pumping stations, under conditions of improper operation, are constantly flooded by groundwater and leaks from pumping units. Therefore, this work focuses on solutions that allow overcoming this production problem by studying the dynamic processes of water accumulation and structural identification of an automatic control system for removing these excesses. Overcoming these flooding processes in the machine hall is achieved by equipping special accumulators and pumping out the excess water that collects in them using a special pump and an automatic control system. The article presents the results of experimental work based on structural identification methods in the MatLab environment. This allowed us to recommend a system for regulating the pumping of excess water based on a PID controller with parameters tied to the production collection tank. Specifically: hmax = 2 m is the maximum water level (overflow level); hon = 1.8 m is the pump on level; hoff = 0.2 m is the pump off level; Qp = 40 L/min is the maximum pump capacity.

1. INTRODUCTION

Sustainable protection against flooding of the machine room of a buried station depends on the reliable operation of submersible pumps that pump out drainage water. In industrial conditions, submersible pumps at some stations, for various reasons, are not able to ensure complete removal of drainage water. In addition to drained water in the turbine room, leaks from pumping units occur, which can be significant. Their volume, together with the drained water, forces the creation of collection tanks to protect the pumping station from flooding. Therefore, the goal of the work was to create a local automated monitoring and control system for these tanks. Taking into account the stated state of the issue with the identified shortcomings arising from operating practice, the possibilities were studied and proposals were made for the use of automation equipment for protecting the pumping station from flooding at the technological site for pumping drainage water. To do this, it was necessary to study the structure and dynamics of the ongoing processes of accumulation of excess water, which leads to emergency situations of flooding.

The general structure of the functioning of a pumping station includes a number of technological sections that are of an auxiliary nature and provide the necessary conditions for automation. At the same time, the nature and dynamic properties of the accumulation of excess water in a special container, which should collect excess water, were investigated. In this case, the pump of this tank must remove this water in a timely manner, automatically. Thus, the functioning of this section, as a control object, provides protection from flooding of the machine room. Figure 1 shows a diagram of this drive as a control object.

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Here it is necessary to select an object in the production process. As the water level in the facility increases, the container itself is first filled, and upon reaching the set height h in it, it begins to flow into the collection tray, and then, with an increase in the flow of water from leaks, drainage, and process discharges, the machine room begins to flood.

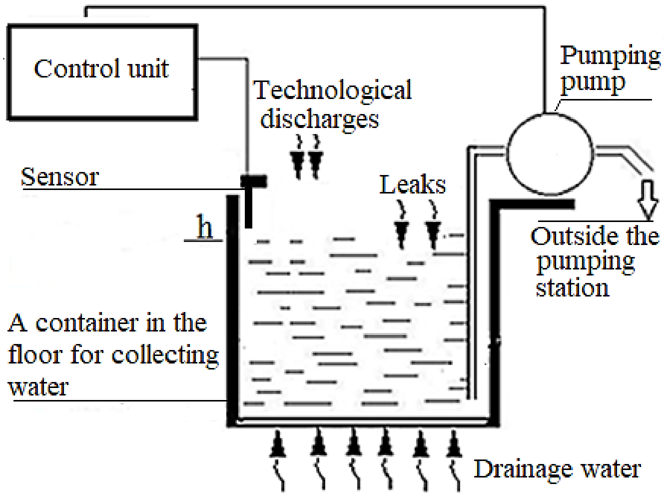

Fig. 1. Water supply to the control object

2. MATERIALS AND METHODS.

In the work it was necessary to investigate the dynamic processes in the control object - in the collection tank. Which in turn ensured the formation of an automatic control system and the use of a controller with a PID control law. The transient process in the object, due to the design of the container, which is deepened, has a filling stage and then overflows into the capacitive channel. It is filled starting from the arrival of water and should end when the specified water level in the facility is reached. It should be noted that water comes in "from above", and these are leaks from pumps and process discharges, and also "from below", this is drained water. In this case, the change in water level at the point where the sensor is installed occurs according to a certain dependence. This dependence involves both fixed and variable parameters. The transition function will reflect the change in water level h in the container depending on a number of parameters, which can be written in general form:

$$h=F(Q1,Q2,Q3) \qquad (1)$$

The input signal in this functional element - the control object - arises depending on the change in the volumes of receipt Q1, Q2, Q3. accordingly, leaks from the machine room, drained water and process discharges, and the output from changes in water level h in the collection tank is measured by a sensor.

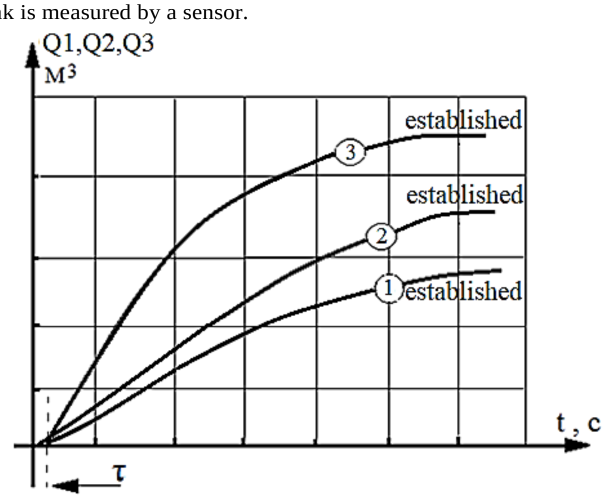

Fig. 2 Dynamic characteristics of the level in the collection tank

Based on the reasoning made, the equation that will describe the mathematical model (balance equation) with a pump-out pump has the following form:

$$A\, dh(t)/dt = Q1 + Q2 + Q3 - Qpump(t) - Qdrain(t) \qquad (2)$$

Specific indicators of process dynamics are characterized, for the production example of our pumping station, by variable parameters:

h(t)—water level in the tank, m

Q1, Q2, Q3 - constant input inflows, m³/s

Qpump(t) — pump flow, m³/s (controlled parameter)

Qdrain(t) — overflow drain flow, m³/s (drain when the level is exceeded),

constant parameters:

A - cross-sectional area of the container, m²

hmax = 2 m - maximum water level (overflow level)

hon = 1.8 m - pump activation level

hoff = 0.2 m - pump switch-off level

Qp - maximum pump performance, m³/s

Cd—discharge coefficient through drain

Ad — drainage area, m²

g—gravitational acceleration, 9.81 m/s2

In this case, the operation of the pump pumping water out of the collection tank is characterized by control from the "off" state to the "on" state, namely:

$$Q_{pump}(t) = \begin{cases} Qp, & \text{if } h(t) \geq \text{hon and the pump is on} \\ 0, & \text{if } h(t) \leq \text{hoff and the pump is turned off} \\ \text{Previous pump status} & \text{otherwise} \end{cases}$$

Water flow through the drain into the collection channel

$$\text{Qdrain}(t) = \begin{cases} C_d A_d \sqrt{2g(h(t) - h_{max})}, & if\ h(t) > h_{max} \\ 0, & \text{otherwise} \end{cases}$$

This equation (2) describes the change in the water level in the holding tank over time, taking into account the total input flow, pump flow and automatic overflow through the drain. The pump control is implemented with hysteresis to prevent frequent switching on and off.

And the dynamic characteristic of the collecting tank will have the form of a first-order aperiodic link with a pure delay in the transfer function:

$$W_{(p)} = \frac{K}{T_1 p + 1} \cdot e^{-p\tau} \qquad (3)$$

where the coefficients are:

T1 -is the time constant of the object, an information indicator of the intensity of water flow into the container;

τ - pure delay of the process in the object;

K - is the transfer coefficient of the object.

3. RESULTS AND DISCUSSION

The analytical description of the transient process of level change represents a dynamic link with a delay. At the same time, it is possible to imagine it in the form of two links connected in series - a link element with a delay and an ordinary linear aperiodic link of the first order (Fig.2)

Pure lag element with transfer function

$$W_{(p)з} = \ell^{-\tau p} \qquad (4)$$

and the element of the aperiodic link of the first order

$$W_{(p)} = \frac{K}{T_1 p + 1} \qquad (5)$$

In general, the object can be represented as a first-order aperiodic link with delay.

$$W_{(p)} = \frac{K}{T_1 p + 1} \cdot e^{-p\tau} \qquad (6)$$

Similarly, other elements of the automatic control system were studied, which will be characterized by the action time τ_1 of all links after the appearance of a mismatch signal in the comparison element, which ensures the activation of the pumping pump. The time τ_2 will be the sum of the time determined by the conditions of signal conversion by the sensor, the operating time of the relay devices of the control system and the time τ_3 of the transient process of the electric motor at start-up, which can, with certain assumptions, occur with very small changes in Q of the object (collection tank), i.e.

$$\tau_{зап} = \tau_1 + \tau_2 + \tau_3 \qquad (7)$$

Quantities τ_1 and τ_2 can be determined by engineering calculations regarding the magnitude $\tau_{зап}$, then it is most advisable to determine it experimentally, by taking the time characteristic. In this case, the value will also be clarified τ_3 as a difference $\tau_{зап}$ and τ_1, τ_2. In this case, the magnitude of the delay τзап can be determined, as stated above, according to experimental data, by constructing a graph of the transient process.

Considering the time $\tau_{зап}$ special assumptions were made, which showed that the $\tau_{зап}$. can vary from 0.1 to 0.25 seconds, compared to the duration of the transient process, which can be up to 80 minutes, with a delay of approximately 0.5%. This makes it possible to accept the object as a first-order link. Thus, the transition function of the considered transient process, the change in water level, can be written as follows:

$$\tau_{зап} = \tau_1 + \tau_2 + \tau_3$$

- when filling in the object

$$h_{(t)o} = kt - kT\left(1 - \ell^{-\frac{t}{60T}}\right) \qquad (8)$$

- when pumping water out of the object

$$h_{(t)3} = kt - kT\ell^{-\frac{t}{63T}} \qquad (9)$$

Based on this and the given dynamic models, a process control flowchart was developed and an automated control system simulation model was created in the MatLab simulink subsystem environment, Fig.3.

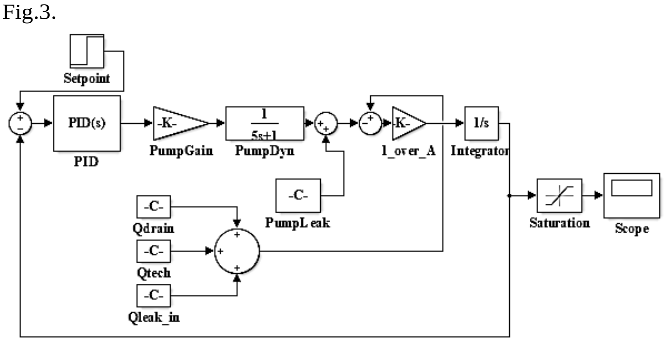

Fig. 3. Simulation model of level control in a composite container

The control system is structurally represented by Fig. 3. The transfer function of the object can be written as:

$$P(s) = \frac{K}{s(T_s s+1)} \qquad (10)$$

To measure the level, a sensor is used, whose mathematical model is written as a first-order aperiodic link (in this model, the time constant is very small, and the desired value can be taken as 1.

$$H(s) = \frac{K}{T_{oc}s+1} \qquad (11)$$

The linear drive model (actuator) is an integrating link with a transfer function

$$R(s) = \frac{1}{T_R s+1} \qquad (12)$$

In an automatic control system, a PID controller is used as a regulator.

$$C(s) = K_c\left(1 + \frac{T_s}{T_v s+1}\right) + \frac{1}{T_1 s} \qquad (13)$$

When building the simulation model, the features of the control process were taken into account. They were related to the need to include inter-tank connections in the water level control loop in the collecting tank.

4. CONCLUSIONS

Research conducted to study the possibilities of automatic protection of submerged pumping stations from flooding has revealed the following:

1. A mathematical model of a storage tank for excess water in the station's engine room, which is an equation of balance between leaks, technological discharges, drained water, and water pumped out of the storage tank.
2. The dynamic characteristics of the water accumulation process in the collection tank, as well as the hysteretic nature of the automatic pumping pump.
3. Build and test an identification model of the automatic control system for pumping excess water based on a PID controller with parameters tied to the production collection tank in the MatLab environment. Specifically: hmax = 2 m is the maximum water level (overflow level); hon = 1.8 m is the pump on level; hoff = 0.2 m is the pump off level; Qp = 40 L/min is the maximum pump capacity.

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