Mathematical description of the groundwater pumping process during the design of the automatic drainage system

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Abstract. The main structure of any building is the foundation. It takes on itself and transfers all its load to the ground. When choosing the type of foundation, the decisive factor is considered to be the characteristics of the soil, the depth of freezing, as well as the level of groundwater, which gives the developer a lot of problems. The foundation under high groundwater level greatly affects the strength and load-bearing capacity of the building and requires a big investment. The groundwater level will be the fundamental criteriawhen calculating the cost of development, construction technology, durability of the structure and operating conditions of the building. The process of designing such systems is significantly complicated by multidimensionality, non-stationarity, as well as the non-linear nature of control objects. When developing an automatic drainage system, it is necessary to build a high-quality mathematical model of the pumping station. The article discusses the process of building an automatic system of groundwater regulation in a drainage tank based on a given control value and disturbing effect. The mathematical description is developed for the control circuit "water level - speed of the drainage pump" with the main disturbing effect - a change in the groundwater supply Mathematical model of the pumping station is implemented using a virtual simulation program - ViSSim.Based on the obtained model, an automatic drainage system can be developed to prevent flooding of the foundation with ground water during the construction of buildings and structures.

1 Introduction

The depth of the underground premises of residential and public buildings and structures does not always flow of drainage water by gravity into the storm drains. In this case, it is necessary to install drainage pumping stations.

When developing an automatic drainage system, it is necessary to build a mathematical model of the pumping station, which is complicated by the significant nonlinear nature of such facilities.

The key control loop of the developed system is the regulation of the groundwater level in the drainage tank. The pumping speed (drainage pump operation) was selected as the

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controlling variable, whereas the main disturbing effect in the system will be a change in the groundwater supply (tank flooding).

2 Materials and methods

Statistical model of the control object is necessary to verify the system operation in steady-state. To buildsuch model, it is necessary to build static characteristics for control and disturbance.

The statistical control characteristic shows the dependence of the controlled variable on the controlling one, namely, the level of groundwater in the tank on the pump speed at a constant feed rate. At various levels of the disturbing value, a set of static characteristics of the control object is obtained in Figure 1 using the ViSSim virtual simulation program. In a similar manner, we obtain a set of static characteristics of the disturbed object.

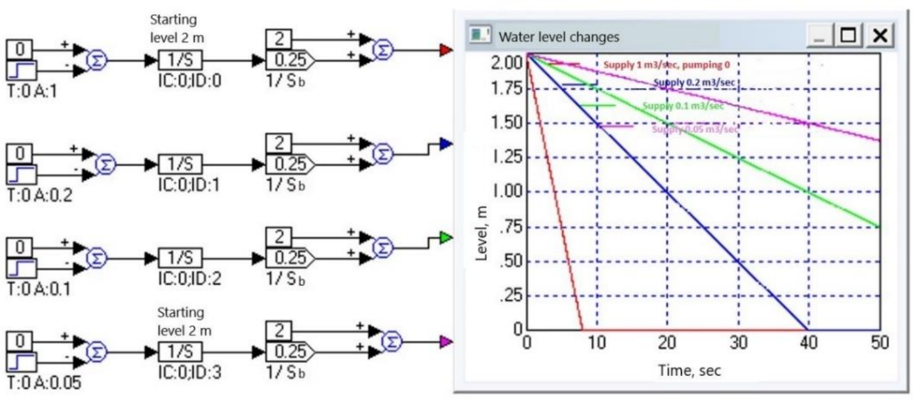

Fig. 1. Dependence of water level on controllingeffect

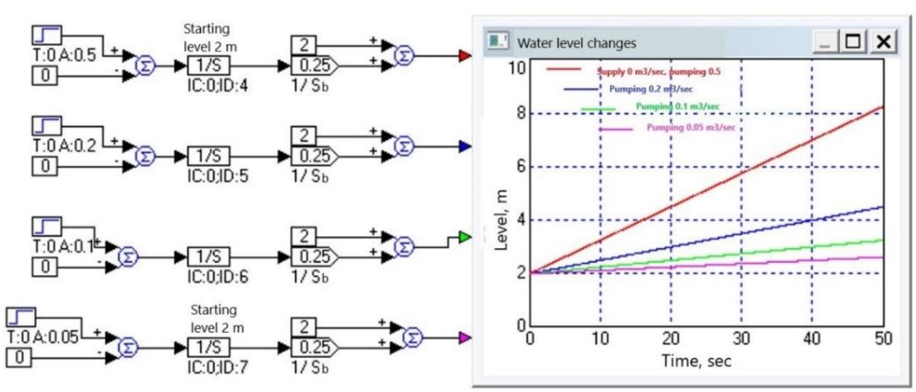

Fig. 2. Dependence of water level on disturbingeffect

It is obvious from the obtained static characteristics of the object that the groundwater level in the tank depends directly proportional on the flow rate and inversely on the pumping speed. However, these characteristics were obtained subject to the linear nature of the control object, and that is not quite the case. To obtain a more reliable pattern, it is

https://doi.org/10.1051/e3sconf/202022201006

desirable to take into account the non-linearity of the elements included in this system. Figure 3 shows a non-linear model of the drainage tank.

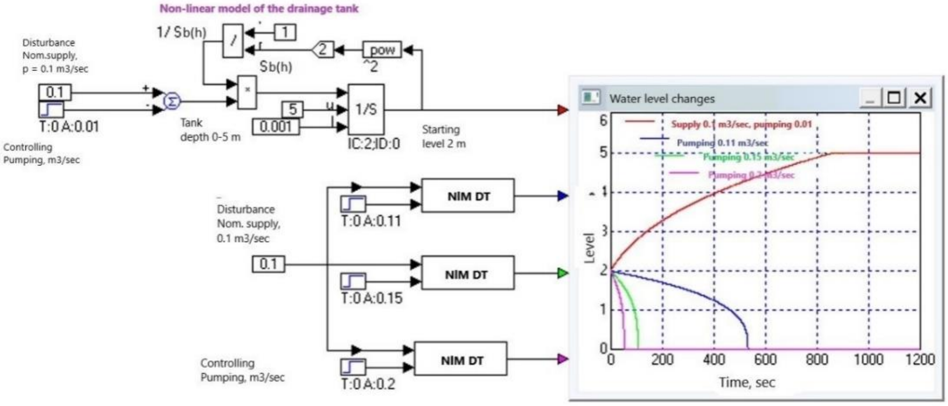

Fig. 3. Non-linear model of the drainage tank

To study the system in transient mode, it is necessary to build a dynamic model that will correspond to the real object in relation to the perception of external effects and the response to them. The dynamic model takes into account the inertia affecting the object properties. It is easier to build a dynamic model in special software systems for systems modeling and study. The system under consideration in Figure 4 was built in the VisSim program.

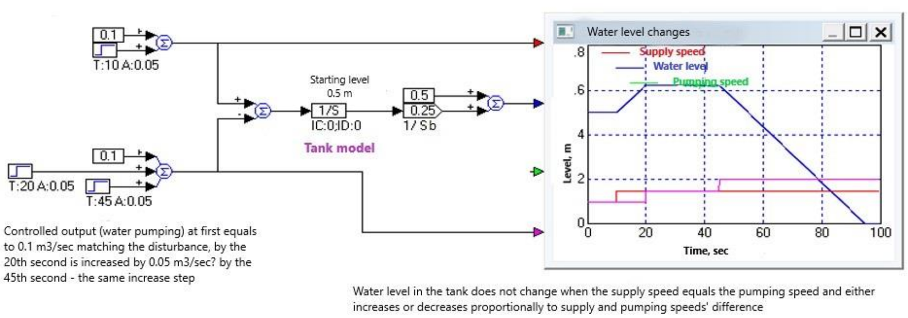

Fig. 4. Dynamic model of the drainage pump

The actuation mechanism in the system under consideration is the drainage pumpfor automatic operation of which the tank is equipped with sensors for switching on and off the pump complex. The trigger level of the main pump is below the level of the supply pipe, and the trigger level of the backup is higher, on the contrary. This eliminates the possible overflow of the accumulator tank. In other words, the backup pump will only turn on when the main pump cannot handle the pumping. In addition, the emergency water level in the tank is also determined. A sensor of this level activates an alarm. The cause for this can be either a failure of the plant equipment or a sudden sharp rise in the groundwater level. This happens during heavy rainfall or breaks of water supply systems in areas adjacent to the building. The level of the pump shutdown point should correspond to the lower level of the vertical intake pipe. This will ensure that air is not pumped into the pipeline system of the station. The logical diagram of the main pump is shown in Figure 5.

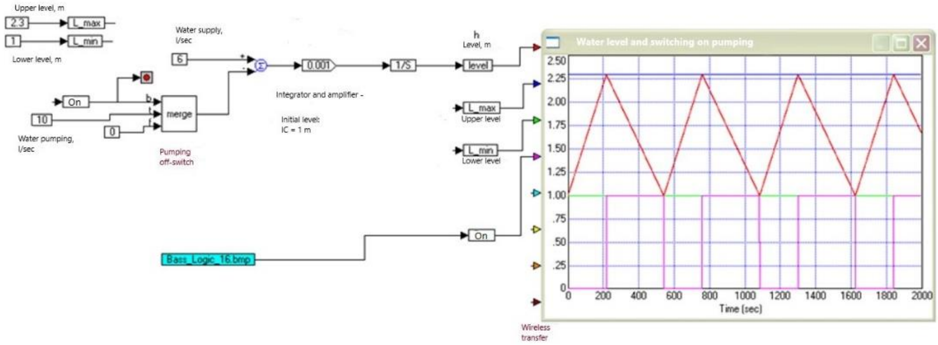

Fig. 5. The logical flow chart of the main pump

The block diagram of the groundwater level regulation in the tank is shown in Figure 6.

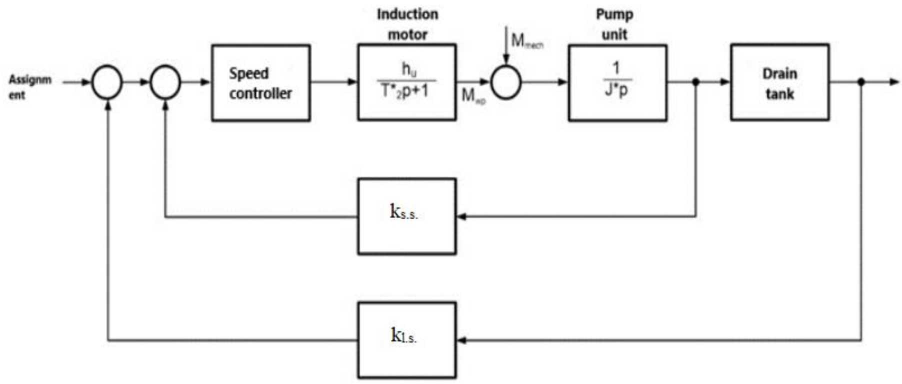

Fig. 6. CAP block diagram

The necessary initial data for calculationof the mathematical model of the pumping unit are given in table 1.

Table 1. Reference data for calculation

Parameter	Designation	Value
Pump specification 1D1600-90		
Rated revolution	n_H	985 rpm
Specification of driving motorAIR355S6		
Rated power	P_{HOM}	160 kW
Rated voltage	U_{HOM}	380/660 V
Rated slip	S_{HOM}	0,015
Rated revolution	n_{HOM}	985 rpm
Active resistance	r_1	0,034 ohm
Induced resistance	x_K	0,63 ohm

3 Results

At the working area of the mechanical characteristic, asynchronous motor can be represented as a first-order factor with a dynamic stiffness transfer function [2]:

$$\mathrm{h}_D(\mathrm{p})=\frac{\mathrm{m(p)}}{\omega\mathrm{(p)}} = -\frac{h_U}{1+T_2'p} \tag{1}$$

where T_2' – time constant of general-purpose engines;

$$T_2' = 0.05\ s.$$

$$\mathrm{h_U} = \frac{2\cdot \mathrm{M_К}}{\omega_{\text{НОМ}}\cdot S_{\text{К}}} = 2 \cdot \mathrm{M_К} \cdot T_2' \tag{2}$$

The moment of inertia of the pump unit is calculated as follows:

$$J = 1.2 \cdot J_{\text{ДВ}} \tag{3}$$

$$J = 1.2 \cdot 9{,}5 = 11{,}4\ kg \cdot m^2$$

Let's determine the rated engine speed using the expression

$$\omega_{\text{НОМ}} = \frac{\pi \cdot n_{\text{НОМ}}}{30} \tag{4}$$

$$\omega_{\text{НОМ}} = \frac{3{,}14 \cdot 985}{30} = 103\text{с}^{-1}$$

The motor rating torque is determined as follows

$$\mathrm{M}_{\text{НОМ}} = \frac{\mathrm{P}_{\text{НОМ}}\cdot 10^3}{\omega_{\text{НОМ}}} \tag{5}$$

$$\mathrm{M}_{\text{НОМ}} = \frac{160 \cdot 10^3}{103} = 1553\ \text{Н} \cdot m$$

The critical torque is calculated as follows:

$$\mathrm{M_К} = \mathrm{M}_{\text{НОМ}} \cdot 1{,}9 \tag{6}$$

$$\mathrm{M_К} = 1553 \cdot 1{,}9 = 2951\ \text{Н} \cdot m$$

Active rotor phase resistance reduced to stator winding:

$$r_2' = S_{\text{НОМ}} \cdot \left(\frac{3\cdot U_{\text{НОМ}}^2}{2\cdot\omega_{1\text{НОМ}}\cdot \mathrm{M}_{\text{НОМ}}} - r_1\right) + S_{\text{НОМ}} \cdot \sqrt{\left(\frac{3\cdot U_{\text{НОМ}}^2}{2\cdot\omega_{1\text{НОМ}}\cdot \mathrm{M}_{\text{НОМ}}} - r_1\right)^2 - (r_1^2 + x_{\text{К}}^2)} \tag{7}$$

$$r_2' = 0{,}015 \cdot \left(\frac{3 \cdot 380^2}{2 \cdot 104{,}7 \cdot 1553} - 0{,}034\right) + 0{,}015 \cdot$$

$$\cdot \sqrt{\left(\frac{3 \cdot 380^2}{2 \cdot 104{,}7 \cdot 1553} - 0{,}034\right)^2 - (0{,}034^2 + 0{,}63^2)} = 0{,}036\ ohm$$

Induction resistance of stator and rotorreduced resistance:

$$x_1 \approx x_2' = \frac{x_K}{2} \tag{8}$$

$$x_1 \approx x_2' = \frac{0{,}63}{2} = 0{,}315\ ohm$$

The critical slip is calculated as follows:

$$S_K = \frac{r_2'}{(x_1 + x_2')} \tag{9}$$

$$S_K = \frac{0{,}036}{(0{,}315 + 0{,}315)} = 0{,}05$$

$$\mathrm{h_U} = \frac{2 \cdot 2951}{103 \cdot 0{,}05} = 1041$$

The mathematical model of automatic pumping station for groundwater is shown in Figure 7.

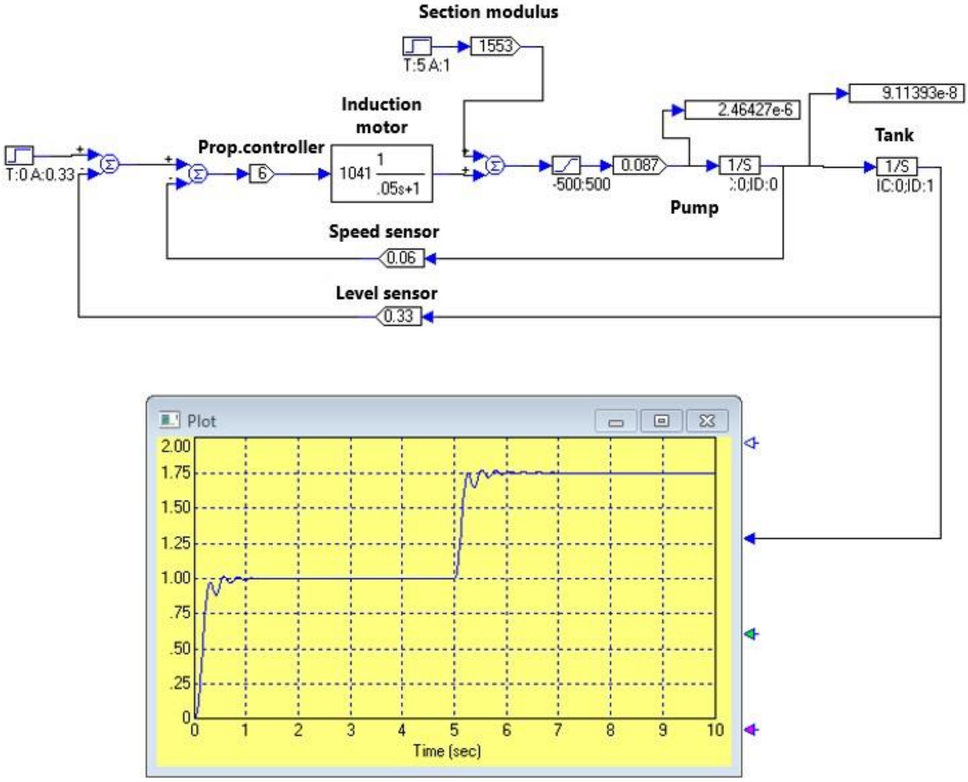

Fig. 7. The mathematical model of automatic pumping station for groundwater

The control law for the pump speed regulator is selected as proportional. The gain ration of P-regulator was obtained by bringing the system to the boundary of stability and multiplying the resulting coefficient by 0.6 [4,5].

4 Conclusions

It is obvious from the transitional changes in the groundwater level that the system is stable. Transient time does not exceed 1 second. The system copes with the disturbance at the same speed. The groundwater level, even in the presence of disturbance, does not exceed the critical mark of 2 meters. The control error in stationary mode is 0. Despite the insignificant oscillation of the circuit, we can conclude that it is advisable to use a simple P-law of regulation and there is no need to use complex control algorithms.

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