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EXPERIMENTAL RESEARCH OF INTERACTIVE ENERGY SAVING CONTROLLER OF WATER SUPPLY PUMP BASED ON FLOW RATE MEASUREMENT

Introduction. The gradual depletion of energy resources and the increase of their costs require from the modern science developing new energy saving technologies. Almost all the solutions in the field of water supply systems for the decrease of pumps' energy consumption and water losses are currently based on the implementation of the frequency-controlled induction motor drives as pump movers [1]. Therefore, all the producers of frequency converters provide their products with an option for forming the «pump» type of the mechanical characteristics of the induction motor. Also a discrete PID-controller is embedded allowing easy cabling standard industrial external pressure or flow rate sensors to implement head (or flow rate) stabilization systems. The head stabilization systems adjusting the pump velocity according to the consumers' water consumption and sometimes also switching on (or off) additional pumps remain the most widespread variants. The water consumption forecasting (prediction) with the following pump scheduling is also frequently used [1]. Despite good results of energy saving of the systems discussed above, the scientists and engineers are still looking the ways for additional energy consumption decrease due to the search of some minimum pump velocity satisfying consumers' requirement. For example, the Gundfos Magna pump reads the water supply system's need and meets its demand at the lowest possible control curve, thus maximizing energy saving [2]. A new direction of research, so-called «interactive» control, has been generated recently. It is based on interplay between the pump control law and corresponding consumers' reaction [3]. The theoretical approaches for the interactive pump control implementation based on flow rate measurement [3] and head measurement [4] have been already developed. But the details of the experimental research are presented only for the second case [5]. In case of the flow rate measurement, the research based only on a hybrid model of the water supply pump is reported [6].

Paper objective. The objective of the paper is to present the results of the experimental research of the interactive pump control based on the flow rate measurement with a modified interactive algorithm where the output current signals of the flow rate sensor are used instead of flow rates values.

Description of the modified interactive control algorithm based on flow rate measurement. The block diagram of the modified interactive control algorithm according to [3,6] is depicted in Fig. 1. The following nomenclature and abbreviations in Fig. 1 are accepted: RE means the Reference Element, SE means the Sampling Element, ZOH means the Zero-Order Hold, T_0 is the controller's sample time, U_{rfn} is the rated referred value of the induction motor's stator voltage frequency, U_{rf1}, U_{rf2}, and x denote intermediary variables, U_{rf} is the referred value of the motor's stator voltage frequency, U_{rfmax}, U_{rfmin} are the maximum and minimum values of U_{rf}, k is a positive gain slightly less than 1, c is a small positive constant to prevent division by zero. The operation of the controller in Fig. 1 is described in [3,6]. The only difference (the modification) is that instead of the flow rate value Q the voltage U_i is used. It is the voltage on a resistor R connected in series to the flow rate sensor with the output signal 4-20 mA.

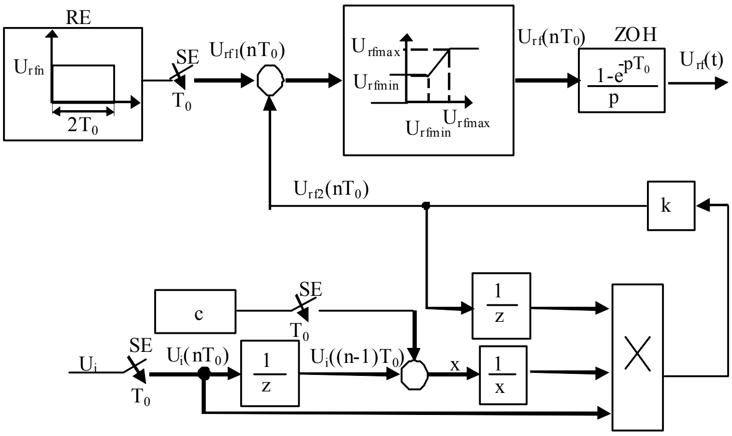

Fig. 1 The block diagram of the interactive algorithm

The equation of the referred value of the induction motor's stator voltage frequency substituting U_i instead of Q [6] will be as follows

$$U_{rf}(nT_0) = \frac{kU_i(nT_0)}{U_i((n-1)T_0)+c} U_{rf}((n-1)T_0), \tag{1}$$

Taking the dependence of the output current of the flow rate sensor on flow rate value is linear gives

$$I = k_i Q + I_0, \tag{2}$$

where I is the output current of the flow rate sensor, I_0 denotes 4 mA, and k_i is the linearization gain.

Then the equation (1) transforms into

$$U_{rf}(nT_0) = \frac{k(k_i Q(nT_0)+I_0)R}{(k_i Q((n-1)T_0)+I_0)R+c} U_{rf}((n-1)T_0). \tag{3}$$

Thus, the modified algorithm differs from the presented in [6] only by the term I_0R both in the nominator and denominator of the formula (3).

Description of the experimental rig. The functional scheme of the interactive control system is shown in Fig. 2.

The system is implemented based on the centrifugal pump Calpeda MXH 202E with the rated power 0.33KWt and three-phase driving squirrel-cage induction motor (the voltage 230V, the velocity 2800 rpm). The stator of the motor is fed by the frequency converter Lenze 8200 Vector with the rated power 0.75KWt. Depending on the positions of the water taps WT1 and WT2 water can be pumped from the tank 1 to the tank 1 and/or to the tank 2. If WT3 is open then water can flow from the tank 2 to the tank 1after some critical level in the tank 2. The back vent BV prevents the pump from the back water flow. The pressure sensor PS MBS3000 is powered from the DC source of the digital ammeter DmA2 based on Autonics MT4W. The current output of the PS (I_H) is connected to the external feedback signal terminal of the frequency converter through the DmA2. The analog output of the frequency converter is assigned to monitor the power (the voltage U_p is proportional to the output power of the converter) by the digital voltmeter DV based on Autonics MT4W. The flow rate sensor FRS Kobold DRS1.15 is connected to the ammeter DmA1 based on OBEH 2TPM0. To meet the requirement of the input voltage (not to exceed 2.56 V) of the interactive controller [5] the voltage U_i is transferred through a divider. According the scheme in Fig. 2 the voltage U_i is

$$U_i = IR_1R_2/(2R_1 + R_2). \quad (4)$$

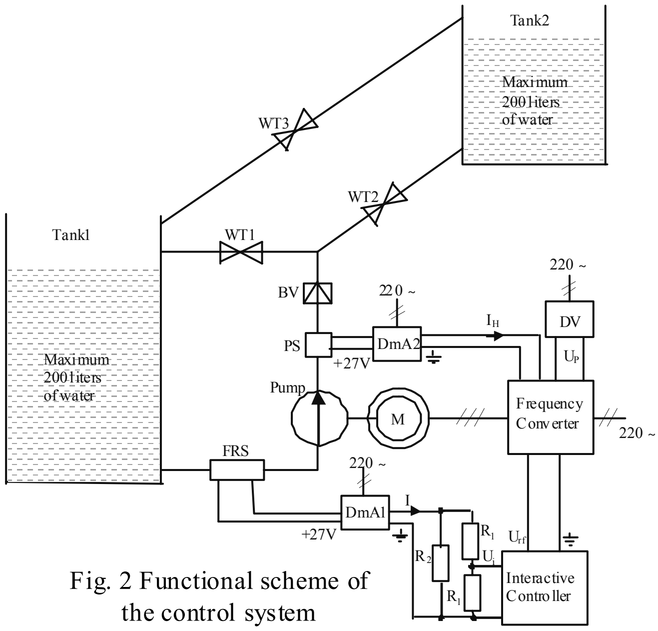

Fig. 2 Functional scheme of the control system

So, the value of R in equation (3) equals $R_1R_2/(2R_1+R_2)$. The output of the interactive controller (U_{rf}) is wired to the frequency converter instead the referred potentiometer. The input terminal of the converter for the referred signal is calibrated for 0-5 V, and the feedback terminal is to be programmed for 4-20 mA.

Results of experiment. Figures 3 and 4 show the operation of the system when there is no response of consumers on the pump velocity change caused by the interactive controller. The sample time T_0 of the controller was 30 seconds. The values of voltages U_{rfmax} and U_{rfmin} were taken 5 and 3 respectively. Water was pumped from the tank 1 into the tank 1. The plots represent the steady-state pump operating points connected by lines (the dependences of the head H and consumed power P on the flow rate Q). The dependences were measured for different k values and two types of the motor mechanical characteristics (U/f=const and U/f^2=const, where U is the motor's stator voltage and f is the stator voltage's frequency). In all the cases the pump's velocity was gradually decreased providing the decrease of energy consumption. For the given value of the hydraulic net resistance, the reduction of the frequency from 50 Hz to 30 Hz provided about 70 % energy saving. In real systems it is necessary to increase U_{rfmin} to provide minimum allowed flow rate. Such a large distance between operating points at lower flow rate could be explained by worse accuracy of the flow rate sensor for this region.

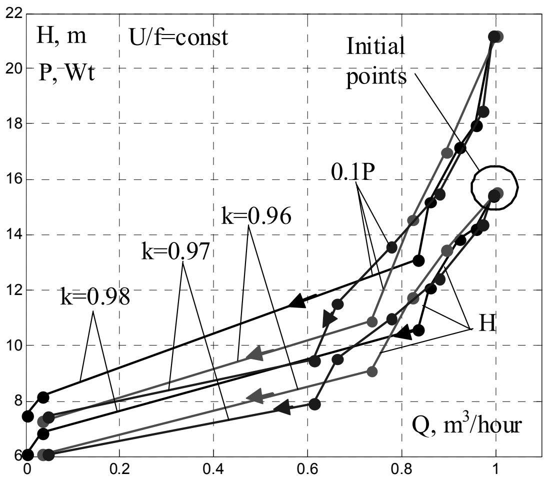

Fig. 3 The operating points without consumers response and U/f=const

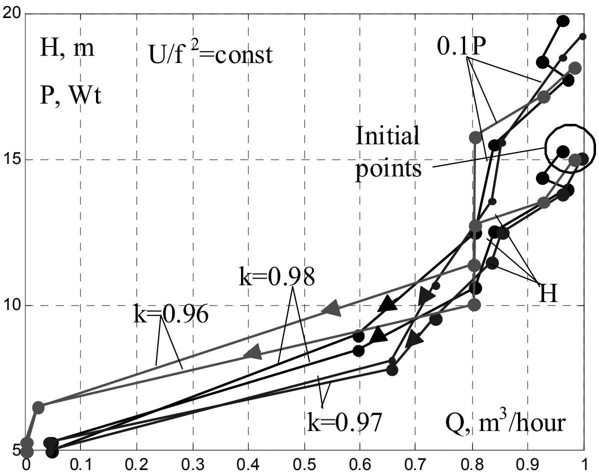

Fig. 4 The operating points without consumers response and U/f^2=const

Figures 5, 6, 7 and 8 demonstrate the operation of the interactive system for different k and U/f laws when consumers respond the changes caused by controller action. The sample time is 2 minutes. For the given condition of system work the energy saving is about 47%. This value will be less for the lower frequency control range which allowed value is defined based on the height of water lifting. The modified interactive control algorithm appeared to be efficient, but it still needs improvement regarding the prevention the operating points with minimum possible hydraulic net resistance (fully open water taps) and the way to renew the interplay. The output signal of the flow rate sensor is more sensitive to the flow rate disturbances than the pressure sensor to the pressure disturbances. As a result it is necessary to provide the control system operation without small flow rate. Otherwise, the water flow through the pipe can influence the sensor's turbine unpredictable way giving sometimes even peak values of the measured flow rate.

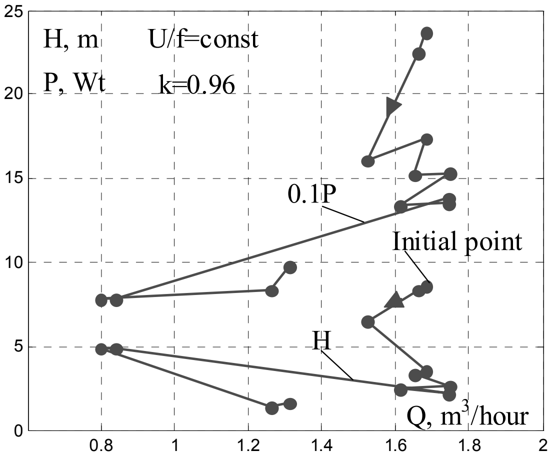

Fig. 5 The operating points with consumers response, k=0.96 and U/f=const

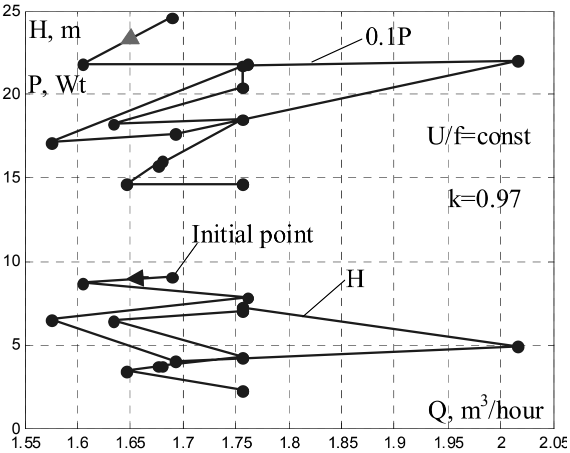

Fig. 6 The operating points with consumers response, k=0.97 and U/f=const

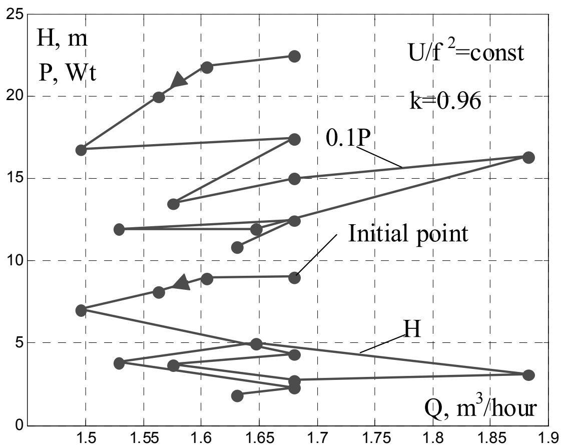

Fig. 7 The operating points with consumers response, k=0.96 and U/f^2=const

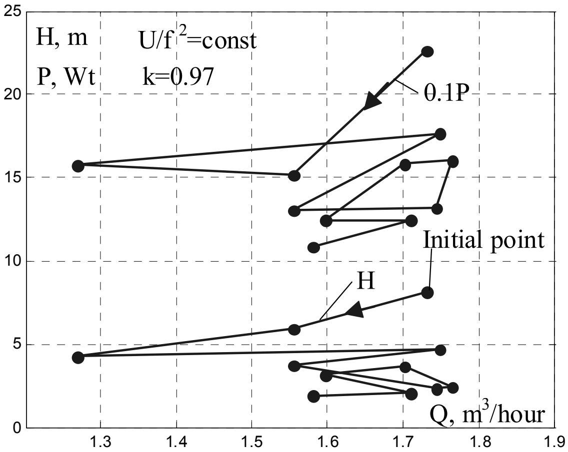

Fig. 8 The operating points with consumers response, k=0.97 and U/f^2=const

Conclusion. It is possible to use in the interactive control laws the output signals of the flow rate sensor not transforming them into flow rate values. The operation of the interactive system is more reliable for the large values of the flow rate. The interactive controller is efficient both for the U/f=const and U/f^2=const types of the mechanical characteristics of the driving induction motors.

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