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# STUDY OF THE CONTROL SYSTEM WITH THE SMITH PREDICTOR AND AUTOTUNING ALGORITHM AT-2 FOR THERMAL CONTROL OBJECTS WITH THE CONSTANT SPEED ACTUATOR

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**Abstract.** The application of the Smith predictor in the control system with a constant speed actuator is considered. In order to make it possible to use the Smith predictor a PID-controller with autotuning is used, the autotuning provides the control object model using a self-oscillation mode. The control object has a second order transfer function with a transport delay. The performance of the system was analyzed on an experimental workbench with the industrial constant speed actuator and a physical model of the control object. Recommendations are given, how to correct the PID-law parameters in order to improve the system performance.

## 1 Introduction

The Smith predictor can be used in order to improve the performance of a control system with a control object with time delay [1, 2]. For effective operation of the Smith predictor an exact model of the control object is necessary, the model must be renewed periodically, and it can be a problem in industrial control systems.

When the Smith predictor is used it is also necessary to correct the controller parameters in order to use the possibility to improve the operation speed of the system, this possibility is provided by the delay elimination regarding to the controller signal. It is necessary to estimate the performance of the system when disturbances influence the control object.

In order to obtain the control object model it is offered to include an autotuning (AT) module into the controller software. The control system with a constant speed actuator widely used in power engineering is considered, therefore it is recommended to use so called AT-2 [3] which provides self-oscillation mode in order to determine the control object mathematical model by means of frequency methods and to calculate the PID-law parameters later.

The aim of the present work is to analyze the performance of the control system with the predictor, PID-controller, constant speed actuator and AT-2, and to give

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recommendations how to correct the PID-law parameters in order to use all possibilities of the control system with the predictor.

## 2 Experimental workbench and autotuning algorithm

The study was carried out on an experimental workbench (see Figure 1) containing a physical model of the control object (it is an electrical heater connected with a laboratory adjustable autotransformer), a constant speed actuator, a programmable controller (Owen PLC 154) and a personal computer.

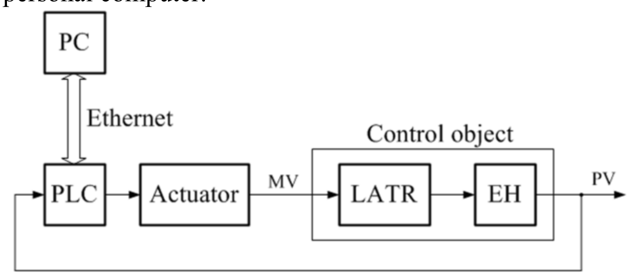


**Fig. 1.** The structure of the control system. PC – personal computer, PLC – programmable logic controller, LATR – laboratory autotransformer, EH – electric heater.

The control action on the object was carried out by means of the heater supply voltage change by the actuator connected with the slider of the autotransformer. The full stroke time for the actuator was 30 seconds.

Programming environment CoDeSys 2.3 was installed on the computer, connected with the controller through Ethernet, CoDeSys allowed to program the controller, obtain, process and archive information about the system operation. In the controller software there was an autotuning module (AT-2) which calculated the PID-law parameters and determined the control object model parameters. The control object model has the second order transfer function with transport delay

$$W_{ob}(s) = \frac{K_{ob} \cdot \exp(-s \cdot \tau)}{(T_1 \cdot s + 1) \cdot (T_2 \cdot s + 1)}, \quad (1)$$

where $K_{ob}$ – transfer constant; $T_1$, $T_2$ – time constants; τ – delay time.

The optimal parameters of the PID-law are calculated using the object model obtained in order to minimize the integral from the control error module, the frequency oscillation index $M$=1.4. AT-2 is used in the software of different controllers, for example, made by Owen company. The PID-law used has the following transfer function.

$$W_{PID}(s) = K_P \cdot \left[ 1 + \frac{1}{T_I \cdot s} + T_D \cdot s \cdot \frac{1}{(T_f \cdot s + 1)^2} \right], \quad (2)$$

where: $K_P$, $T_I$, $T_D$, $T_f$ – the transfer constant, time constants of integration, differentiation and filtering; $T_f = T_D/8$.

Transient processes in the control system when the AT-2 is operating are given in Figure 2. When $t \approx 400$ s the operation of AT-2 finishes and the system begins to work in the control mode.

The AT-2 calculated the following parameters:

– The object model parameters: $K_{ob}$=183.5; $T_1$=13.3 s, $T_2$=240.4 s; τ=12.6 s;

– The PID-law parameters: $K_P$=6.36; $T_I$=58.6 s; $T_D$=13.3 s.

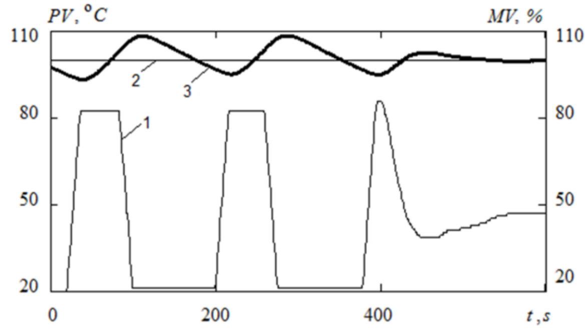


**Fig. 2.** Transient processes when AT-2 is operating. 1 – the signal from the actuator, *MV*, %; 2 – the setpoint signal, *SP*, °C; 3 – the control object output (the heater temperature), °C.

The block diagram of the control system with the Smith predictor is given in Figure 3. The predictor is built on the basis of the control object model with two outputs, one of them has the transport delay and the other does not, the control object output is also used in the predictor. This structure was used because the control system was based on the programmable controller using event-driven libraries.

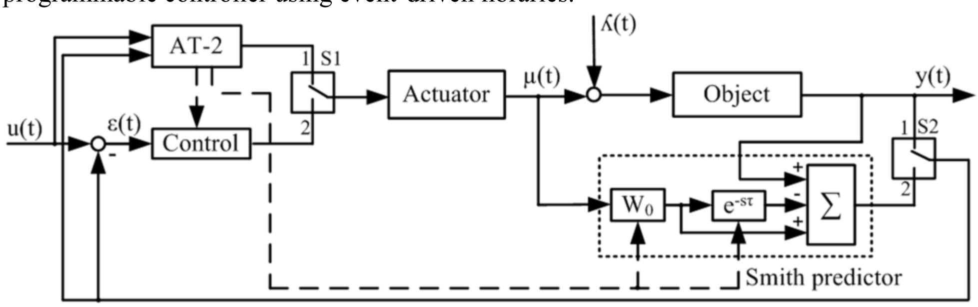


**Fig. 3.** Block diagram of the control system with the Smith predictor.

## 3 Experimental results

The performance of the control system was estimated by the transient processes when the setpoint was changed and when the step disturbance *ΔMV* influenced the control object. The step disturbance was created moving the LATR slider in the manual mode. The setpoint was changed by 5°C (from 100 to 105°C), the disturbance *ΔMV* was 20%.
The following variants of the control system parameters were considered:

- The PID-law parameters calculated by the AT-2, no predictor;
- The PID-law parameters calculated by the AT-2, the Smith predictor included;
- The Smith predictor included, the calculated PID-law parameters were corrected using the correction coefficient $k$=2 ($K_P$ was doubled).

The transient processes when the setpoint was changed are given in Figure 4.

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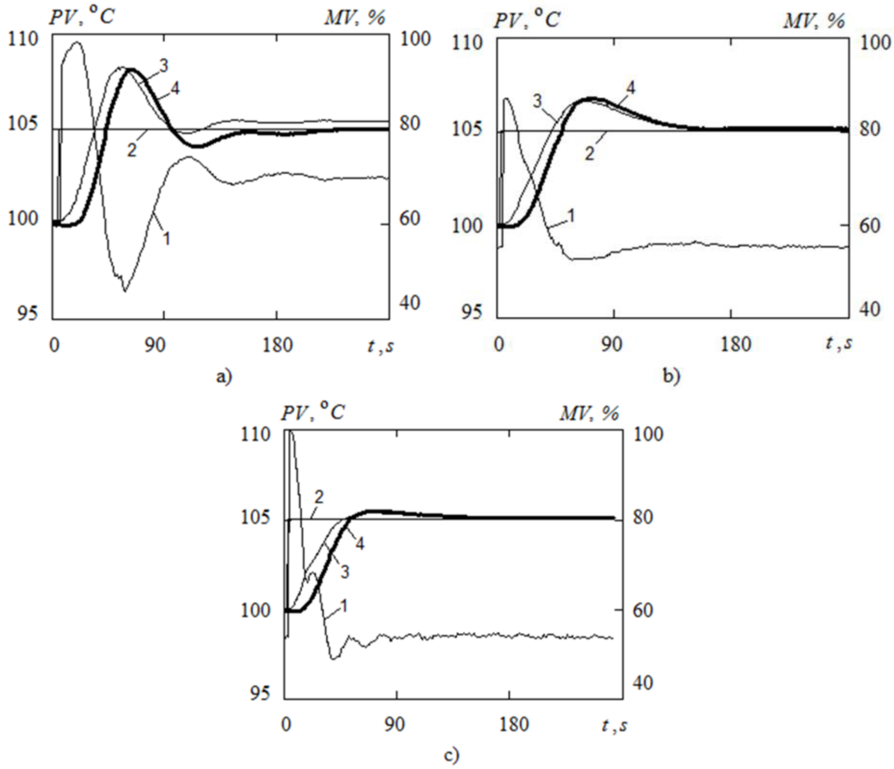


**Fig. 4**. The transient processes when the setpoint was changed: a)no Smith predictor; b) the Smith predictor is operating, the calculated PID-law parameters are used; c) the correction coefficient $k$=2.0. 1 – *MV*; 2 – *SP*; 3 – the output of the predictor; 4 – *PV*.

The control system performance can be characterize by the overshoot $\delta = PV_{max} - SP$, the settling time $T_{cntr}$ and the damping degree. The process with $k$=2.0 (see Figure 4c) can be considered the best. The overshoot and the settling time for this case are considerably lower than for the process where the PID-law parameters calculated by AT-2 are used (see Figures 4a and 4b).

The transient processes for the case when the step disturbance acted on the control object are given in Figure 5.

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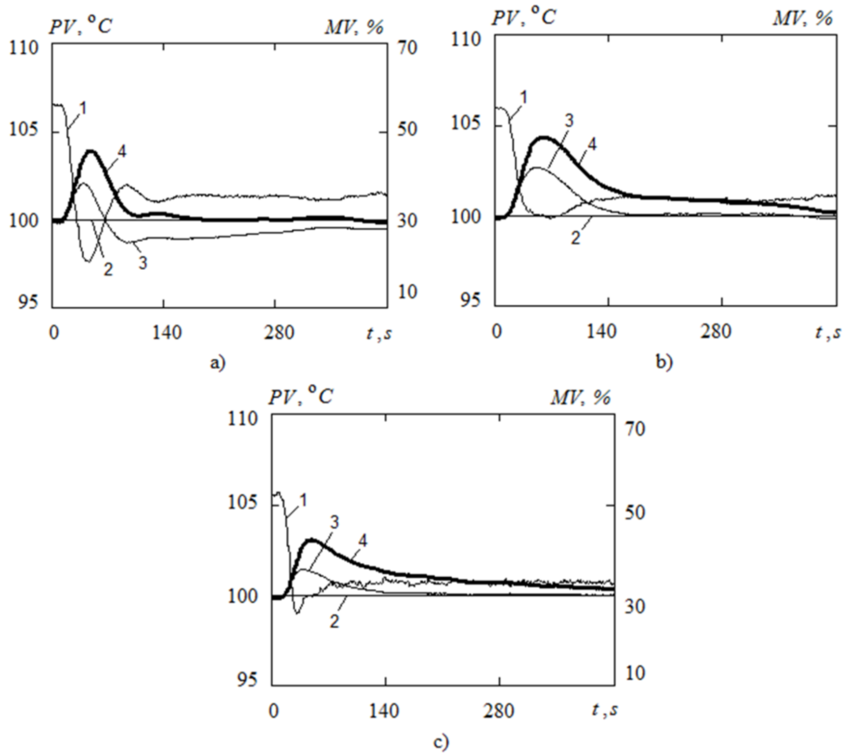


**Fig. 5**. The transient processes when the step disturbance acted on the control object: a)no Smith predictor; b) the Smith predictor is operating, the calculated PID-law parameters are used; c) the correction coefficient *k*=2.0. 1 – *MV*; 2 – *SP*; 3 – the output of the predictor; 4 – *PV*.

## 4 Conclusion

According to the experimental results given above the following conclusions can be made:

- When the correction coefficient *k*=2 the overshoot is minimal, though the settling time is rather long.
- When the correction coefficient is higher than two, the transient process becomes oscillatory, it is inadmissible.
- In this case it is unsuitable to correct the time constants of the PID-law.
- The use of the Smith predictor in the control system with a thermal control object with time delay is suitable when the setpoint changes often during the operation of the system. For this case it is recommended to use the correction coefficient *k*=2 and to correct the transfer constant calculated by the AT-2.
- If the setpoint is mainly constant and remarkable disturbances influence the control object, the effectiveness of the Smith predictor is doubtful.

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