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Improving the Accuracy of Temperature Control inside Dry-Air Sterilizer Oven by Using Prediction Algorithm

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ABSTRACT *: The article is devote to the temperature control of objects with lumped or distributive parameters. The problems of keeping a predetermined temperature are discussed. The major attention is paid to the process of maintaining the temperature inside dry-air sterilizer oven. It is shown that the temperature in insulated sterilizer chamber depends not only on the power of the heater but also on the power of the fan. It is concluded that pulse-width modulation with prediction filter algorithm provides good quality control.*

KEYWORDS *-dry-air sterilizer oven, object with distributive parameters, object with lumped parameters, predictive filter, PWM-modulation, temperature control, transient function*

I. INTRODUCTION

At the current stage of human development, the consumption of energy resources is steadily increasing, while the efficiency of their use remains at a fairly low level. The depletion of natural energy resources and increasing electricity production costs causes countries of the world looking for energy efficiency improved technologies. Hundreds of scientific papers by leading scientists of the world are devoted to the problems of efficient use of heat.

The energy consumption of residential and commercial buildings is one of the main source of worldwide power consumption. There is a large variety of thermal systems in industry and everyday life that need to be monitored — it's heating and cooling systems, temperature control of spacecraft, industrial processes, etc.

These systems are usually complex and include a diversity of physical processes, some of which are nonlinear - convection, radiation, a complex geometric shape, the dependence of the properties of control object on temperature, non-linearity, hydrodynamic instability, turbulence, or chemical reactions. To study these systems analytical, experimental or computingapproaches are used.

Most algorithms of thermal control are designed for solving the so-called "direct tasks", that are usually considered from a cause-consequence position. The purpose of the solution of "direct tasks" of heat exchange is to obtain the temperature of the whole body using the dependence of the heat flux and temperature on the boundary of a solid body. Searching the amount of control action on thermal object requires the solution of the inverse heat conduction problem — at the present time for a given temperature distribution is searching the control action that was already in the past. This control action is generated on the basis of predictions the future behaviour of the object.

Using predictive algorithms allow producing the required amounts of the heat to reduce power consumption and the total work time of the heater. Furthermore using prediction control algorithms will allow to reduce the temperature of the air in a room to the minimum level at night and turn on the heater and increase the air temperature to the setpoint at the beginning of the working day.

The main problem in implementing the optimal energy-saving control of thermal processes is the lack of real-time algorithms for the implementation of control actions. The World's leading manufacturers of domestic and foreign automation (Matlab, Siemens, Schneider Electric, Omron, Motorola, etc.) are trying to find solution to this problem.

The results of conducted energy efficiency calculation studies demonstrate that using the technology of microcontroller-based systems with control algorithms in industry can reduce heat costs.

II. OBJECT DESCRIPTION

The building — is a large object that can be called as an object with distributed parameters. Properties of the building space are not uniform. To maintain the temperature in the building it is necessary to divide its structure on a large number of object volumes where the properties of these volumes are different from each other. The next step isto provide temperature control for each volume (objects with lumped parameters) of air. Alternatively, a single air volume may be considered as a temperature air in the sterilizer chamber.

Sterilizers are used for air disinfection and sterilization of medical devices, for drying glass or metal objects. On-Off, PID controllers are used to control the temperature in sterilizers, as in most industrial processes [1]. PID

controllers are used in the processes with a small value of dead time. At the present time there are a large number of PID tuning algorithms for stable and unstable processes with a large and a small quantity of the dead time [2]. The most popular method of setting PID controllers for processes with small value of dead time is the Ziegler-Nichols algorithm [3]. Prediction control is used in systems that have the large dead time or require high precision control.
The dry-air sterilizer oven GP-80 (Fig. 1) was selected as a control object.

Figure 1: The object of control (sterilizer GP-80)

This dry-air sterilizer oven has four-temperature sterilizing modes (85 °C, 120 °C, 160 °C and 180 °C) and three time scale (30 min., 45 min., 60 min.) of maintaining the temperature.
Temperature that can be maintained in the sterilizer is in the range of 85 ± 8 ° C, 120 ± 8 ° C, 160 ± 8 ° C, 180 ± 10° C, i.e. the maximum relative temperature error is + 9.4%, ± 6.6% , ± 5%,± 5.5%.
The object of research is the temperature control loop inside dry-air sterilizer oven. Traditionally, for the solution of the problem of maintaining the temperature inside dry-air sterilizer oven of this brand applying on-off controller that realized on a resistor divider. Therefore, due to the using of an on-off controller, the accuracy of temperature control is reducing because of the resistors values drift. Also, employing an on-off controller, that realized on a resistor divider makes impossible to utilize the other temperature control algorithms.

To increase the accuracy and quality of temperature maintaining inside the dry-air sterilizer oven we offer temperature control with using microcontroller devices with predictive control algorithms.

III. PROBLEM FORMULATION

Using an on-off controller in the temperature control process leads to unnecessary spending of resources caused by temperature overshoot. Also, additional resources are consumed due to the change of thermal process parameters for the sterilization processes.
The main purpose of this research is applying of the pulse-width modulation (PWM) control method with the prediction [4] for more precise temperature maintenance.

IV. PREDICTION ALGORITHM

PWM control with the prediction filter [4] has been selected as the method of object temperature control.
The structure of hardware system includes the following devices:
1) Microcontroller ATMega 16 with algorithm of PWM control with predictive filter.
2) Temperature sensor DS18B20.
3) EEPROM memory AT24C256.
Temperature sensor was located inside sterilizer, in the center of the camera volume.
Firstly it is necessary to obtain the transient response of the object without heater and external influences.
A feature of some types of dry-air sterilizer is the presence of the fan in the bottom of the camera, designed for heat distribution in the chamber. Since the camera is well insulated, so the fan is a heater itself. Therefore, the transient response of dry-air sterilizer oven without external disturbances will consist of a transient response of the fan. (Fig. 2).

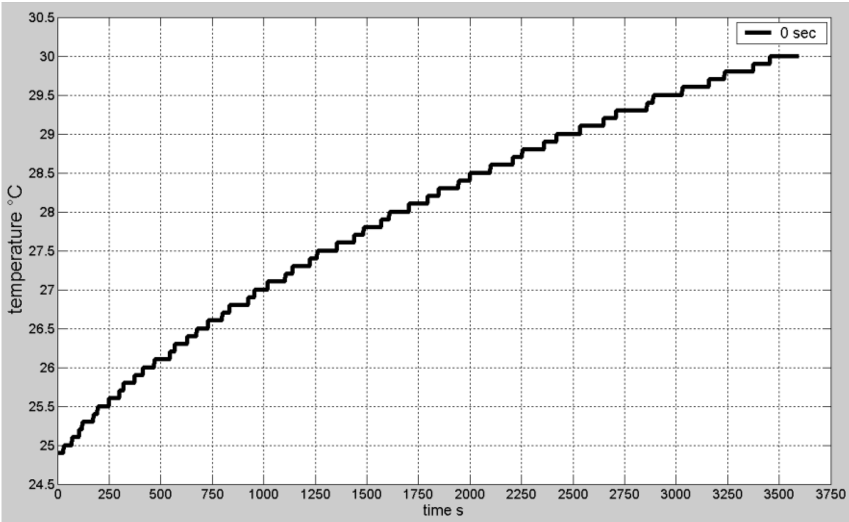

Figure 2: Transient response of the fan

Then it is necessary to get the transient response of the heater without external influences. Since the fan is working all the time, we will subtract the resulting transient response from the received transfer characteristics of the fan (Fig. 3). Since temperature sensor DS18B20 has an upper limit of measurement of 125 °C, we stopped obtaining the transient response at a value of the time equal to 555 sec.

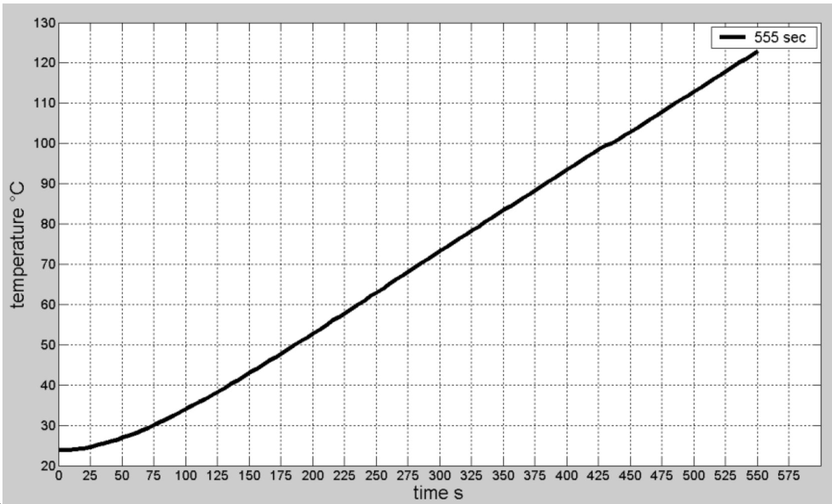

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Figure 3: Transfer characteristics of the object without fan

Then we need to divide the obtained time of transient response (555 seconds) on the equal parts (for example sampling time t_d = 25 sec) and obtain transient characteristics of the object under the influence of the duration of the pulse signals $j \cdot t_d$ (Fig. 4).

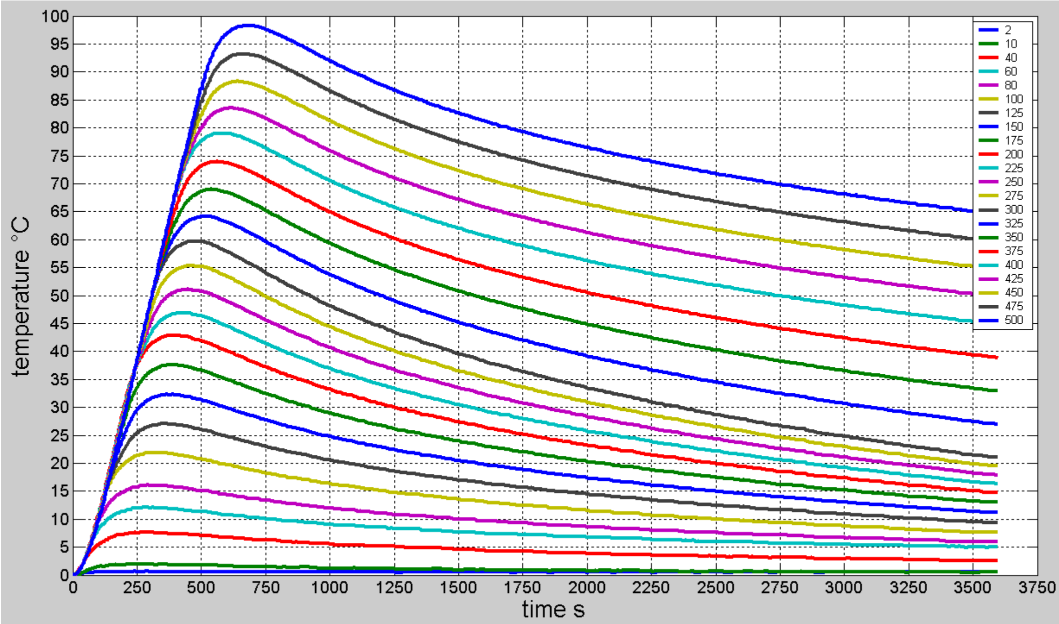

Figure 4: The reaction of the object on a predetermined thermal control action.

In the points $j \cdot t_d$, where $j \cdot t_d = 1 \cdot t_d, 2 \cdot t_d, \ldots, N \cdot t_d$ – output signal values (temperature) $\Theta_1, \Theta_2, \ldots, \Theta_N$ are measured. Heat transfer coefficients $\eta_{i,j}$ of thermal field in time j are calculated by Eq. (1).

$$\eta_{i,j} = \left.\frac{\Delta \theta_i}{Q \cdot t_{dj}}\right|_{t_{dj} = t_d \cdot j}, \qquad (1)$$

$\Delta \theta_i$ – increment temperature of the i-point interval, °C;

Q – thermal flux power, W;

$t_{d,j}$ – pulse width, s.

After that the calculated coefficients (1) need to be written in the EEPROM memory.

To perform the experiments of maintaining the temperature in dry-air sterilizer oven the following temperature conditions were chosen (Fig. 5).

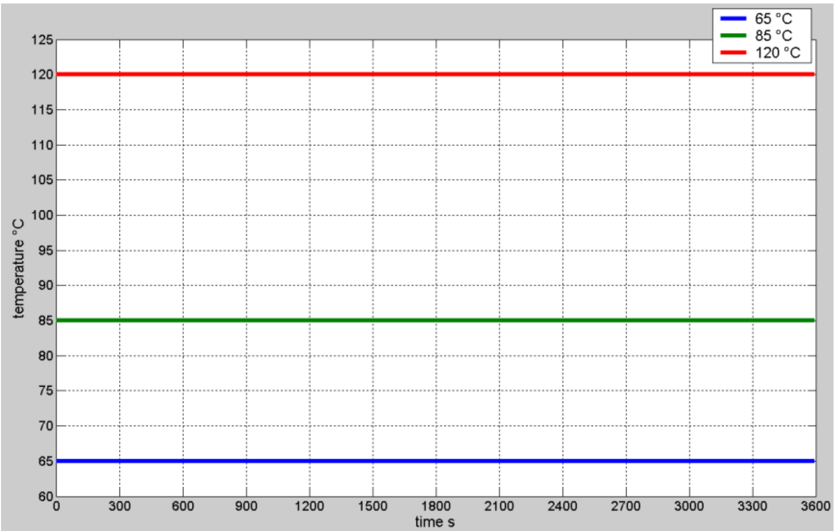

Figure 5: Thedesiredtemperature

When the control system is starting, software begins the calculation of the prediction changes relative to the initial temperature Θ_0.

At the time interval $j \cdot t_d$, where $j \cdot t_d = 1 \cdot t_o, 2 \cdot t_o, ..., N \cdot t_d$ the total deviation Δ of current and predicted temperature from required temperature is calculated by Eq. (2).

$$\Delta = \Delta_1 + \Delta_2 = \Delta\Theta_j^Z - \Delta\Theta_j^R + \Delta\Theta_{j-1}^Z - \Delta\Theta_{j-1}^D \quad , \qquad (2)$$

$\Delta\Theta_j^Z$ – required object temperature, °C;

$\Delta\Theta_j^R$ – one interval ahead temperature prediction, °C;

$\Delta\Theta_{j-1}^D$ – the current temperature of the object, °C;

t_d – the sampling period, s.

According to the Eq. (3) heat exposure durations are calculated.

$$\Delta t_d = \frac{-\Delta}{Q \cdot [\eta]}, \qquad (3)$$

Q – thermal flux power, W; $[\eta]$ – an array of heat transfer coefficients.

The results of maintaining the desired temperature (Fig. 5) are shown at Fig 6,Fig. 7 and Fig.8.

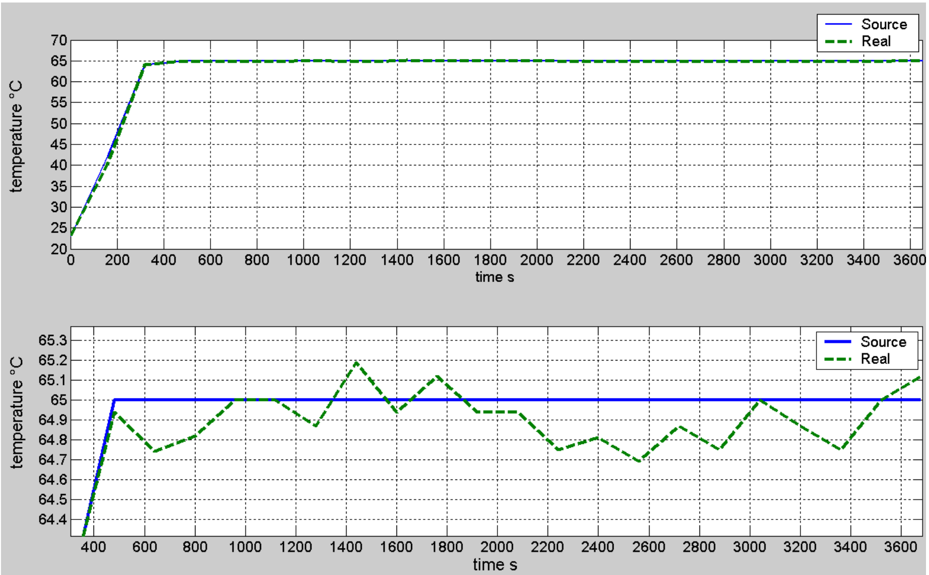

Figure 6: The result of maintaining the desired temperature (65 °C).

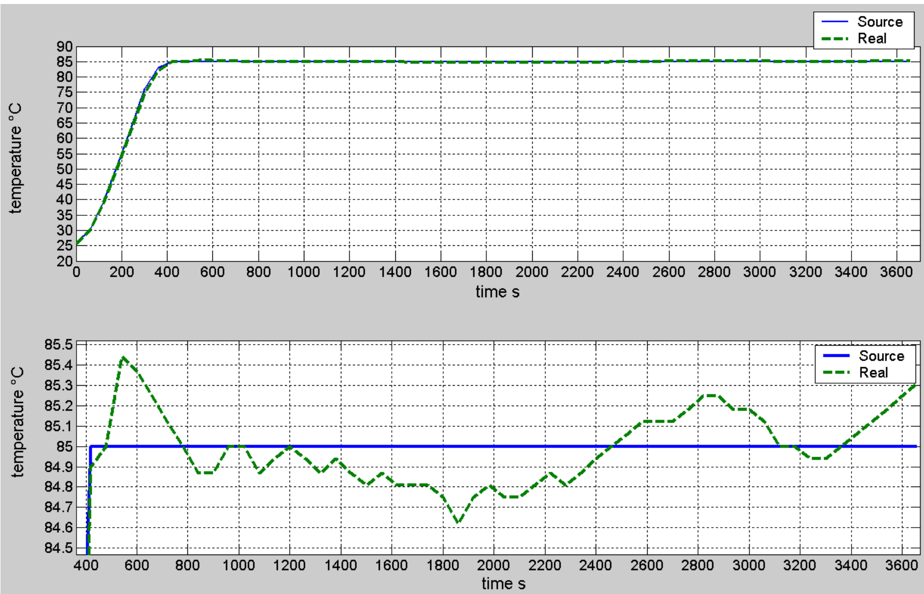

Figure 7: The result of maintaining the desired temperature (85 °C).

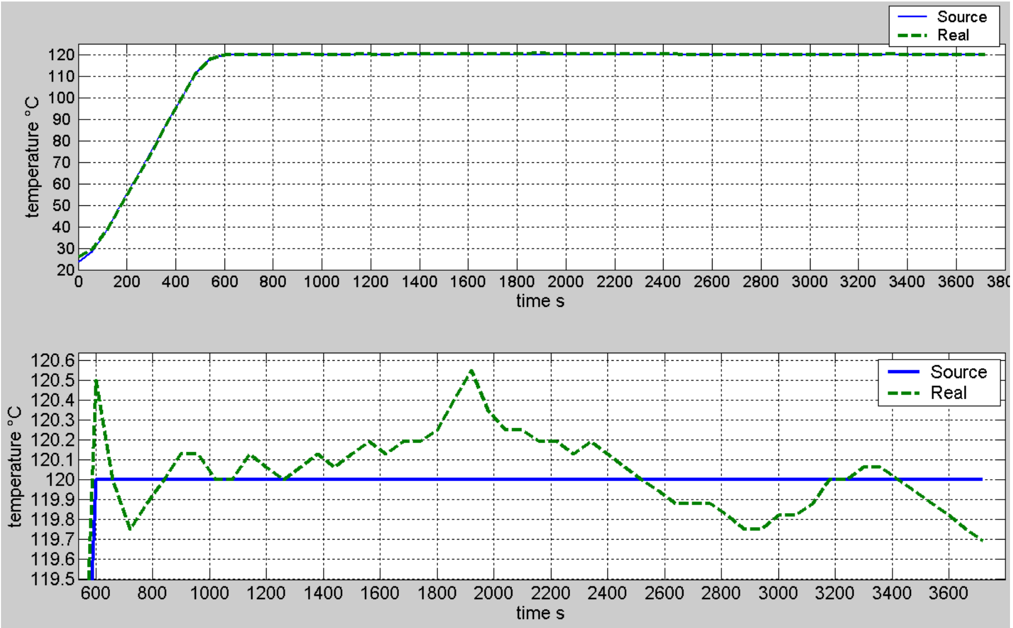

Figure 8: The result of maintaining the desired temperature (120 °C).

Experimental results are presented in Table 1.

Table 1:Theresultsofexperiments

Desiredtemperature, °C	Max. absolute temperature error, ° C	Max. relative temperature error, %	Temperature overshoot ratio, %
65	0.2	0.3	0.07
85	0.35	0,4	0,4
120	0.5	0.42	0.42

V. CONCLUSION

The control method of PWM-modulation with prediction for thermal objects was proposed. Experiments of maintaining the require temperature of the dry-air sterilizer oven was made. The results showed fairly good accordance between the required and obtained values. Prediction control should use for systems that have the large dead time or require high precision control. To increase the accuracy of temperature maintaining we need to enhance the number of prediction intervals and to reduce the sampling time t_d .

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