Searching for Optimal Control Parameters of Thermal Object Using Pulse-Width Modulation (PWM) Control with Predictive Filter

Oleg Yevseienko, Anatoliy Gapon, Dmytro Salnikov

Automation and Control Systems Department,
National Technical University "Kharkov Polytechnic Institute",
UKRAINE, Kharkov, Frunze street 21,
E-mail: sendmeyouremail@mail.ru

Abstract* – *The thesis is devote to the temperature control of objects with lumped or distributed parameters. The problems of choosing the right value of regulator's heater power and prediction period are discussed. The major attention is paid to the process of searching the minimum value of control quantities. It is shown that the approximated second-order plane has an exact accordance with the original data. It is concluded that algorithm of PWM-control with prediction filter provides good quality control.

Key words – object with distributed parameters, object with lumped parameters, transient function, PWM-modulation, predictive filter, dead-time, temperature control.

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. According to the European Commission, the United Nations, the level of useful energy is only 40 %, the proportion of useful end-use fuel is less than 20 %. However, the problems of environmental pollution, the exhaustion of high energy raw material reserves and increasing energy costs require urgent solution.

Given the complexity of the socio-economic situation in Ukraine and other countries of the world, even the problem of saving resources for heating residential and office space becomes really topical, while the major importance for humanity is still the need for enormous amounts of heat consumed by industrial processes.

II. Literature Analysis

Hundreds of scientific papers by leading scientists of the world are devoted to the problems of efficient use of heat. Computer-Aided Design (CAD) systems have been designed to speed up and simplify the process of modeling inherently complex heating and cooling processes.

However, the solutions for automation of the processes proposed by various companies are based mostly on the thermostatic regulators operating on a relay or Proportional-Integrative-Derivative (PID) control law [1]. These approaches do not take into account the properties of an object of management, i.e. distribution, linearity, self-regulation, as well as unique characteristics of the object.

III. Plant Model and Process Description

The aim of my thesis is to develop methods to control the temperature of the object under the specified control law and predict its changes in a specified time interval.

One of these methods is the pulse-width modulation (PWM) control with predictive filter [2]. Heater control is directly based on the experimentally obtained characteristics of the object under control.

A steel pipe has been taken as the test object with lumped parameters (Fig.1). The first sensor was chosen to investigate the PWM control with predictive filter method. This sensor was located approximately 5mm away from the bottom of the heater.

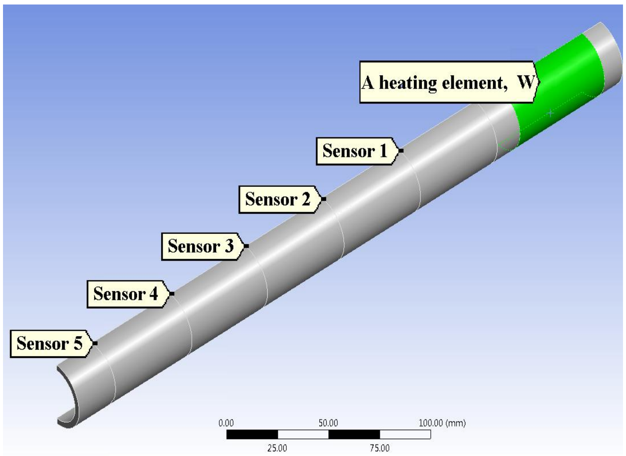

Fig. 1. Control object

Firstly, transient response of the control object were received. Secondly, the dead-time was calculated. After that the reaction of the object to the pulses of predetermined duration from dead-time (50 s) till 200 s with increment equal to 10 s and heater power equal to 5 W, 11.25 W, 15.87 W and 25 W were obtained. These curves have the same shape. Fig.2 shows the results of experiments in which heater power is equal to 25 W.

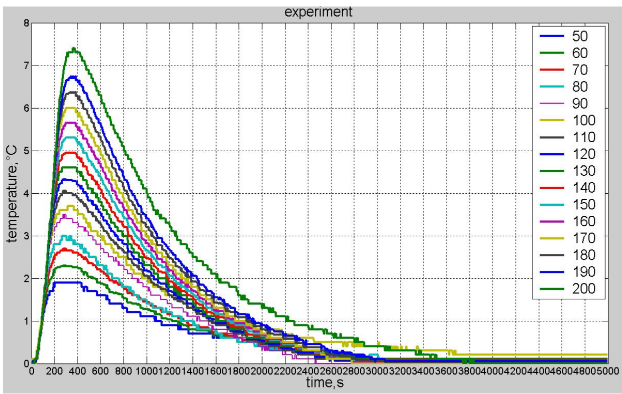

Fig. 2. The reaction of the object on a predetermined thermal control action

As a result of the experiments, datasets of heater power, pulse duration and control accuracy that equals to the temperature overshoot divided by temperature in the end of the pulse were obtained.

To find the minimum value of the control parameters it is necessary to determine the extremum. First of all the equation of the object function need to be obtained. To approximate the equation Ordinary Least Squares (OLS) method had been selected. The chosen set points are presented in Table 1.

TABLE 1

SELECTED SET POINTS

Point No.	*X*, *W*	*Y*, s	*Z*
1	11,25	200	1.4/1.25
2	25	170	3.6
3	5	80	0.4/0.15
4	15,87	150	1.9/1.2
5	5	200	3/4
6	5	100	5/3

For the approximation the plane with Eq.(1) had been selected.

$$z = a{\cdot}x^2 + b{\cdot}y^2 + c{\cdot}x{\cdot}y + d{\cdot}x + f{\cdot}y + g\,. \qquad (1)$$

Using Matlab approximated plane was calculated Eq.(2) and built at Fig.3.

$$z = \frac{147}{22063}\cdot x^2 + \frac{9}{26449}\cdot y^2 - \frac{48}{105367}\cdot x\cdot y + + \frac{89}{2117}\cdot x - \frac{334}{3065}\cdot y + \frac{1487}{165}\,. \qquad (2)$$

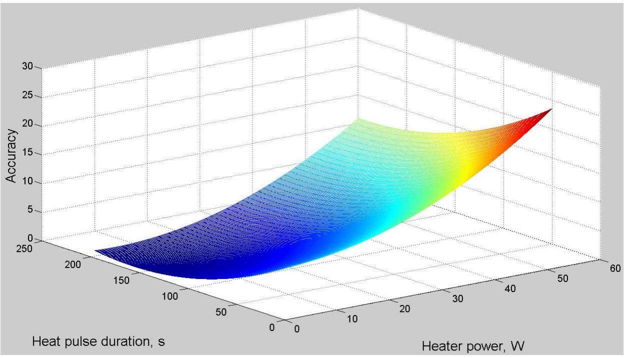

Fig. 3. Approximated plane

Using the second partial derivative the minimum point equal to 2.3734 W and 161.71 s was found.

Using extremum parameters transient curves were again obtained. The resulting time duration as the sampling period for the control method was chosen.

In the points $j\cdot t_u$, where $j\cdot t_u = 1\cdot t_u, 2\cdot t_u, \ldots, N\cdot t_u$ – output signal values (temperature) Θ_1, Θ_2, ..., Θ_N are measured. Heat transfer coefficients $\eta_{i,j}$ of thermal field in time j are calculated by Eq. (3).

$$\eta_{i,j} = \frac{\Delta\theta_i}{Q\cdot t_{uj}}\bigg|_{t_{uj} = t_u\cdot j}, \qquad (3)$$

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

Q – thermal flux power, W; $t_{u,j}$ – pulse width, s.

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 $j\cdot t_\partial$, where $j\cdot t_\partial = 1\cdot t_\partial, 2\cdot t_\partial, \ldots, N\cdot t_\partial$ the total deviation Δ of current and predicted temperature from required temperature is calculated by Eq (4).

$$\Delta = \Delta_1 + \Delta_2 = \Delta\Theta_j^Z - \Delta\Theta_j^R + \Delta\Theta_{j-1}^Z - \Delta\Theta_{j-1}^D\,, \qquad (4)$$

$\Delta\Theta_j^Z$ – 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_∂ – the sampling period, s.

According to the Eq.(5) heat exposure durations are calculated.

$$\{\Delta t_u\} = \frac{-\Delta}{Q\cdot[\eta]}, \qquad (5)$$

Q – heat flow power, W;

$[\eta]$ – an array of heat transfer coefficients.

The results of maintaining the set temperature using obtained extremum parameters are shown at Fig.4.

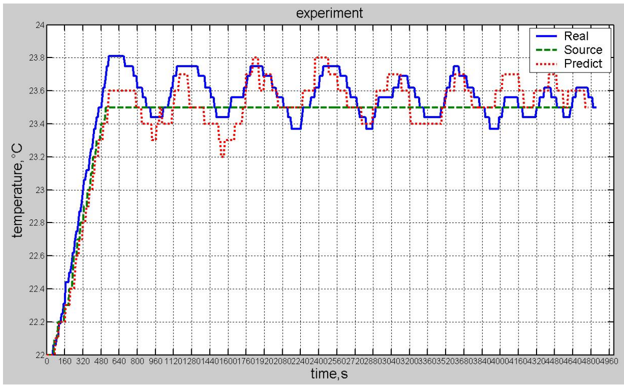

Fig. 4. The result of maintaining the desired temperature of the object

The maximum deviation of actual temperature from the required temperature was 0.25°C.

Conclusion

The control method of PWM-modulation with prediction for thermal objects was proposed. The process of finding the optimal parameters of heater control was presented. An experiment of maintaining the require temperature of the object was made. The results showed fairly good accordance between the required and obtained values.

References

[1] M. A. Johnson and Mohammad H. Moradi, "*PID Control. New Identification and Design Methods*". – London, UK: Springer, 2005, 543 p.

[2] S. M. Savytskyi, A. I. Hapon, P. O. Kachanov, O. M. Yevseienko and V. O. Vyskrebentsev, "*Sposib prohramnoho upravlinnia teplovym obiektom z zastosuvanniam shyrotno-impulsnoi moduliatsii*" ["*Method of controlled thermal object using pulse-width modulation*"], Useful model patent no.81276, UA81276U. June, 25, 2013.