OPTIMIZATION OF THE DYNAMIC CHARACTERISTICS OF TECHNOLOGICAL PROCESSES

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Abstract: *This work represents one of the methods of simulation of the objects of industry. Its chief characteristic is the determination of mathematical dependence between the input and output parameters by using the numbers of Volterra of the second kind. On the basis of mathematical models of the dynamics, the theory of variational calculus is defined optimization technique of dynamic characteristics of the process.*

INTRODUCTION

At the present stage of engineering and technology development, the automatization of processes plays a crucial role. This is urgent for all branches of industry, including those of food and processing. The systems of automatization of the processes in food industry must satisfy such requirements as accuracy, constancy, reliability and operational simplicity. Therefore, engineers come across a complex problem, the essence of which consists in the creation of automatization systems, which satisfy the criteria pointed out above. An important step here is the original modeling, which is the basis for the optimization of process parameters. An important step here is the original modeling, which is the basis for the optimization of process parameters.

The purpose of this paper is to reveal the essence of mathematical description of technological processes in the dynamics, as well as the use of methods for describing the dynamic characteristics and the search for their optimal values. In this case study will cover the process of polycondensation of the polymer.

To achieve the presented goal it is necessary to solve the following tasks:

- to select the most acceptable method of simulation for the process under investigation, with the use of which the basic special features of the object simulated will be considered;

- to conduct the identification of the dynamic characteristics, obtained as a result of the object study;

- on the basis of this mathematical description of the object to develop a method of finding optimal values of the dynamic characteristics.

The simulation of the dynamics of production units is directly connected with a number of researches on plotting of dynamic curves. In the course of studies of this type the instruments already existing in the production and the systems, which continuously record the basic parameters of the process, are used.

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SIMULATION

Before starting the experiment on plotting of dynamic curves of a control object under investigation, it is necessary to develop a procedure on its conducting. There are many procedures; however, the essence of the majority of them consists in the introduction of the disturbing action into the system: single step input, harmonic oscillations, step action and other

Fig. 1 represents the reaction of the system to a single action. It is evident according to the graph that the object is inertia; therefore changes occur not sharply, but with a certain delay.

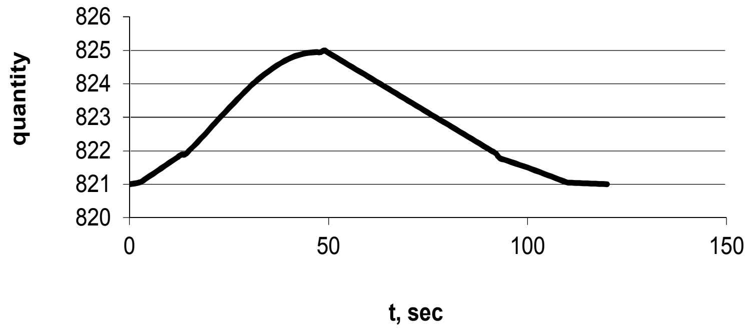


Fig. 1 – The graph of the change in the parameter of the subject of the study with the introduction of the disturbing action into the system.

The description of nonlinear object with the help of the linear on the parameters models seems ideal, since the following properties are inherent in linear objects:

1) the possibility to write down clearly the connection between the entrance and the output;
2) simplicity of the description of the system connections;
3) the possibility of examining random signals.

The properties outlined above must be preserved, also, for the nonlinear objects (Eykhoff,1975). For this we will use decomposition by Volterra.

Using the numbers of Volterra, the nuclei of which are the weighting functions of higher orders, it is possible to obtain the description of a nonlinear object, allowing clear physical interpretation. This method has a large advantage, connected with the fact that a nonlinear system is looked at as the direct generalization of a linear case, although the object itself can differ significantly from the linear one. In other words, the method with the use of numbers of Volterra interprets linear objects as the sub-class of nonlinear objects (Zadeh, 1964).

The essence of the method consists in the fact that with existing input information x(t) and output data y(t) it is necessary to select, using decomposition by Volterra, such a dependence which would be a good approximation y(t).

In the first approximation, let us be limited by $y_{lin}(t)$, determined from the formula (1)

$$y_{lin}(t) = h_1 x_1 \Delta t + h_2 x_2 \Delta t + ... = \sum_{i=1}^{N} h_i x_i \Delta t \qquad (1)$$

where h_i is the amplitude, Δt is the pulse width.
With the condition

$$\lim_{\substack{\Delta t \to 0 \\ N \to \infty}} \sum_{i=1}^{N} h_i x_i \Delta t = \int_0^t h_1(\tau) x(t-\tau) d\tau \qquad (2)$$

where τ is time delay, we have the following expression (3):

$$y_{lin}(t) = \int_0^t h_1(\tau) x(t-\tau) d\tau \qquad (3)$$

When supplying two pulses of input signals x_i и x_j to the object in the form of a linear term of decomposition (in the limit $\Delta t \to 0$, $N \to \infty$) will look as follows:

$$y_{qadr}(t) = \int_0^t \int_0^t h_2(\tau_1, \tau_2) x(t - \tau_1) x(t - \tau_2) d\tau_1 d\tau_2 \quad (4)$$

Thus, we will obtain that $\overset{=}{y}(t) = y_{lin}(t) + y_{qadr}(t)$ (5)

The expressions for the terms are substituted from formulas (3) and (4) respectively into formula (5).

Consequently, the expansion in the Volterra series is the direct generalization of the model of the linear object in the form of convolution integral. The weighting function h (t) of the linear system is substituted by the weighting functions (Bedrosian, 1975).

Thus, the primary task is the determination of the analytical form of the nuclei $h_1(\tau)$ и $h_2(\tau_1, \tau_2)$, as well as the parameterization $\overset{=}{y}(t)$ relating to y(t).

We will use weighting functions of basic dynamic sectional as the kernels of integrals: the integrating, differentiating, periodic component of the second order, as an amplifier.

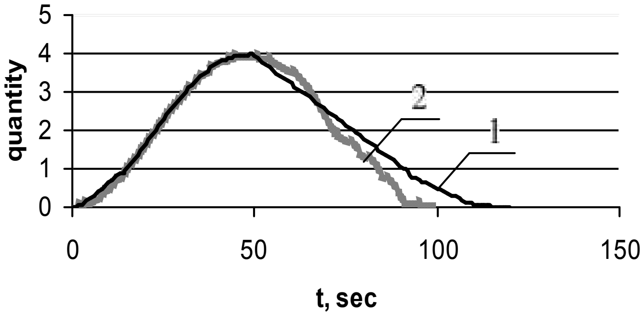
We will conduct the estimation of the accuracy of the expression selected for the approximation on the basis of the condition:

$$(y(t) - \overset{=}{y}(t))^2 \to \min \quad (6)$$

I.e., the square of the difference between the experimentally obtained values of points and the values, obtained analytically, must approach the minimum (let us designate this expression through φ).

Let us apply this method of the identification of dynamic characteristics to the data, represented in Fig. 1.

The work of the aperiodic component of the second order to the integrating component is the nucleus of the number of Volterra. This form of nucleus is selected because the established accuracy of approximation f = 1,144 with its use, is the highest.



1- dependence, obtained experimentally; 2 - dependence, obtained analytically

Fig 2 - the approximation of the output given by a number of Volterra of the second order

Taking into account expression (6) and the nuclear structure of the integrals of the first and second orders, the form of the number of Volterra is the following:

$$\overset{=}{y}_2(t) = \int_0^t \delta(t - 14) x_2(\tau) d\tau + 1.104 \int_0^t \int_0^t (e^{-0.002t} - e^{-0.003t}) x_2(t - \tau_3) x_2(t - \tau_4) d\tau_3 d\tau_4 \quad (7)$$

Dependence (7) of output data on the input pointed out above is represented for one control channel. However, in the real systems there can be several control channels.

OPTIMIZATION

Since in the process of polycondensation, the greatest interest, such as the output variables of the melt viscosity at the outlet of the reactor core and the pre-polycondensation - $\nu_1(t)$, $\nu_2(t)$ and the consumption of PET - $Q_1(t)$, $Q_2(t)$, then the instantaneous values errors in these variables will be as follows:

$$e_\nu(t) = \nu_i(t) - \nu_i^M(t) \tag{8}$$

$$e_Q(t) = Q_i(t) - Q_i^M(t) \tag{9}$$

where $\nu_i^M(t)$ и $Q_i^M(t)$ – the instantaneous values of the viscosity and flow of the polymer obtained from the simulation.

Must take into account the instantaneous values of the error function of the degree of polymerization, which is also the output variable:

$$e_{DP}(t) = DP_i(t) - DP_i^M(t) \tag{10}$$

In the expression (10) the instantaneous values of degree of polymerization $DP_i(t)$ taken from the experiment.

In addition to the output variables should be included in the optimization criterion and control variables: the temperature $T_1(t)$, $T_2(t)$ and the pressure $P_1(t)$, $P_2(t)$ inside the reactor polycondensation. In the process under study there is a need to determine the reaction rate actuator for changing control mode, so we take into account and the rate of change of the control variables in the form of their time derivatives. Thus, the instantaneous values of error function of the control variables and their derivatives have the form:

$$e_T(t) = T_i(t) - T_i^M(t), \quad e_P(t) = P_i(t) - P_i^M(t) \tag{11}$$

$$\dot{e}_T(t) = \dot{T}_i(t) - \dot{T}_i^M(t), \quad \dot{e}_P(t) = \dot{P}_i(t) - \dot{P}_i^M(t) \tag{12}$$

where $T_i^M(t)$, $P_i^M(t)$ и $\dot{T}_i^M(t)$, $\dot{P}_i^M(t)$ – the instantaneous values of temperature, pressure, and their derivatives, obtained by simulation.

Ultimately, the quality criterion characterizes the overall error for the entire period of the control system from some initial values of time $t = t_n$ to the end of the process $t = T$. Therefore, the criterion is the sum of the instantaneous values the basic variables of the process error, integrated over the time of the system.

It is known that the system is not observed monotonic processes, characterized by constant change of sign errors, and therefore to eliminate the dependence on the sign of the error calculation, we use the integral quadraticing estimate.

Thus, for the optimization criterion we take the functional, which is a function of squared errors (8) – (12) and has the following form:

$$\begin{aligned} I(t) = \int_0^T \Psi(t)(\alpha(\nu_1(t) - \nu_1^M(t))^2 + \beta(\nu_2(t) - \nu_2^M(t))^2 + \chi(Q_1(t) - Q_1^M(t))^2 + \\ + \gamma(Q_2(t) - Q_2^M(t))^2 + \psi(DP(t) - DP^M(t))^2 + \eta(T_1(t) - T_1^M(t))^2 + \lambda(P_1(t) - \\ - P_1^M(t))^2 + \mu(T_2(t) - T_2^M(t))^2 + \pi(P_2(t) - P_2^M(t))^2 + \theta(\dot{T}_1(t) - \dot{T}_1^M(t))^2 + \\ + \rho(\dot{P}_1(t) - \dot{P}_1^M(t))^2 + \sigma(\dot{T}_2(t) - \dot{T}_2^M(t))^2 + \xi(\dot{P}_2(t) - \dot{P}_2^M(t))^2)dt \end{aligned} \tag{13}$$

where $\Psi(t)$ – feature that provides a system to achieve steady state; α, β, χ, γ, ψ, η, λ, μ, π, θ, ρ, σ, ξ – weights that determine the trade-off between the main variables of the process, as well as additional conditions on the rate of change of control variables.

As the function Ψ (t) will use proposed in the literature (Andreev, 2006), the expression of stabilization:

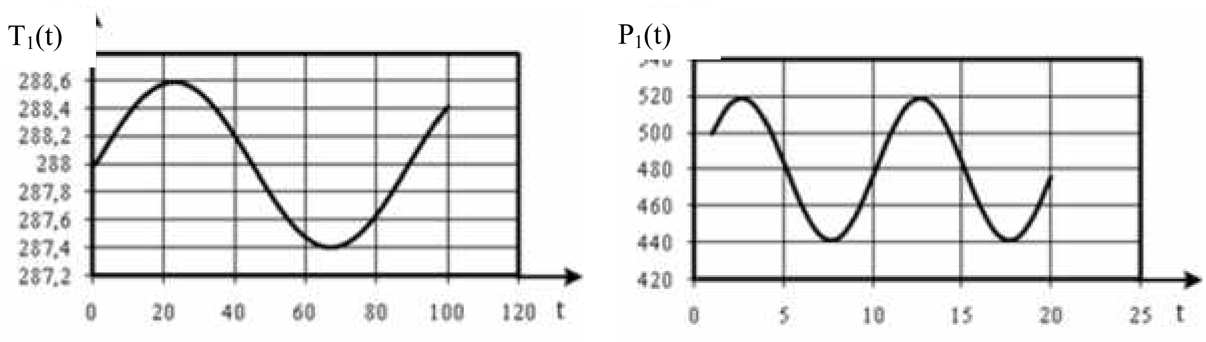
$$\Psi(t) = \frac{1}{2} e^{\frac{2t}{T}}$$

As has been previously stipulated, to find the optimal values of control variables, we use the theory of calculus of variations. In particular, this optimization method to determine the optimal control signal is not only depending on the desired output, but also as a function of the current state of the dynamic process. In addition, since the object under study is nonlinear, the control system is also nonlinear, depending on the shape of the Euler-Lagrange equations (Zelikin, 2004).

Thus, the integrand of the criterion (13) is denoted by F (t). The function that minimizes the functional (13) must satisfy the differential equation of second order Euler-Lagrange equations:

$$\frac{\partial F(t)}{\partial T_i(t)} - \frac{d}{dt}\left(\frac{\partial F(t)}{\partial \dot{T}_i(t)}\right) = 0 \qquad (14)$$

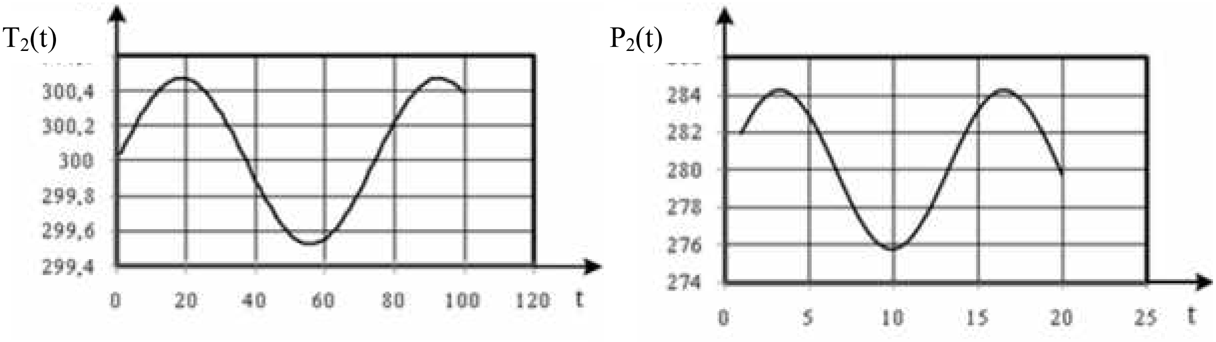
The structure of the integrand is the sum of squared errors of the input and output variables, control variables and the squared errors of the derivatives of the control variables. This is dictated by the need to comply with the conditions of the theorem of Euler-Lagrange equation by which the functions of controls should be continuously differentiable on the interval.
Figures 3 and 4 is a visual representation of the results of the calculations.



a) b)

a) the temperature inside the reactor, PPK, b) the pressure in the reactor PPK

Fig. 3 - Graphs of the optimal control variables pre-polycondensation reactor



a) b)

a) the temperature inside the reactor DPK, b) the pressure in the reactor DPK

Fig. 4 - Graph of optimal control variables polycondensation reactor core

Analyzing the graphs presented in Figures 3 and 4, we can conclude that the optimal values of control variables are subject to a harmonic law.

CONCLUSIONS

The goal has been achieved. The following results have been taken:

1) by means of integral Volterra series, the functional relationship between input and output values with high accuracy (expression 7) has been defined;

2) with use of an integral quality criterion (expression 13), optimization of all process control parameters is performed;

3) the solution of the integro-differential equations system is graphically represented (expression 14). It is optimal for the parameters of technological process control.

LITERATURE

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