Parametric identification of the process of preparing ceramic mixture as an object of control

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Abstract. Manufacture of ceramic materials and products largely depends on the preparation of clay raw materials. The main process here is the process of mixing, which in industrial production is mostly done in cross-compound clay mixers of continuous operation with steam humidification. The authors identified features of dynamics of this technological stage, which in itself is a non-linear control object with distributed parameters. When solving practical tasks for automation of a certain class of ceramic materials production it is important to make parametric identification of moving clay. In this paper the task is solved with the use of computational models, approximated to a particular section of a clay mixer along its length. The research introduces a methodology of computational experiments as applied to the designed computational model. Parametric identification of dynamic links was carried out according to transient characteristics. The experiments showed that the control object in question is to a great extent a non-stationary one. The obtained results are problematically oriented on synthesizing a multidimensional automatic control system for preparation of ceramic mixture with specified values of humidity and temperature exposed to the technological process of major disturbances.

1. Introduction

The technological stage of ceramic mixture preparation while producing such building materials as expanded clay and bricks, is to a great extent a determinant in terms of getting products with the following stable characteristics: strength, density, definite dimensions, certain number of structural cracks, etc. [1-7]. The process of mixing, though, consists not only in obtaining a homogeneous mixture (as Paper [8] states) but also in ensuring stable values of humidity and temperature. That's why this process requires complex analysis.

In clay mixers, which are most often used to prepare the mixture, humidity stabilization systems with a direct current sensor or a moisture sensor are usually used [9, 10]. Humidity sensors here can be installed at the inlet of the mixer, at its outlet or both. There are two types of systems used now for control of the process of mixing and its quality. Systems of the first time are based on the assumption that the highest quality of mixing can be achieved when a certain angular velocity of shafts and can be referred to systems of shafts speed regulation [11]. Systems of the second type are based on another assumption stating that the achievement of the best possible quality of mixing can be provided by the required degree of clay mixer filling [10]. The degree of filling here is controlled according to an indirect parameter - the stator current of motor operator of blade shafts. The degree of filling is regulated by a belt-conveyer feeder.

At the stage of ceramic mixtures formation in an auger extruder while producing bricks temperature stabilization system is used. Steam discharge coming into the mixer is used as control action during this process [9].

For sustainable brick production with a given strength [12-14] humidity and temperature error should not exceed ± *1 %,* which is not provided by existing systems of automatic control of mixing [12]. This is due to the apparent instability of physico-chemical characteristics of clay mixture, as well as variations in faucets technological operations. We believe that in these conditions the implementation specified requirements for humidity and temperature of ceramic mixture can most effectively be achieved by creating modern automated control systems [3, 15-19]. Their synthesis requires prior development of a mathematical model of a clay mixer, adequately reflecting the processes. It is also necessary to make and parametric identification of the created model of ceramic mixture as a control object preparation.

2. Materials and methods

The control object under consideration presents a set of processes of hydration, mixing and temperature changes in clay mixture during its motion along the longitudinal axis x of the caly mixer. The state of the object is characterized by humidity $w_m(x,t)$ and temperature $T_m(x, t)$ of the ceramic mixture in any section $x \in 0,...,L$; L here is the length of the mixing chamber.

For controlling action we take massive steam discharge $G_s(t)$ as well as additional water $G_w(0,t)$, with temperature of T_w. G_S and G_w can be varied by controlling elements provided for by the design of the mixer [12]. In the assumption that temperature T_w and steam temperature T_s are constant, we believe that the main disturbance effects affecting the process come from humidity $w_{cl}(0,t)$ and temperature of clay, loaded into the mixer, $T_{cl}(0,t)$.

In the face of assumptions and simplifications, justified in Paper [12], the process of clay mixture preparation (as applied to evenly distributed character of steam supply along the length of the mixer) in the mixer can be described by a system of differential equations of mass transfer and thermal conductivity in carrier stream [20]:

$$\left.\begin{aligned}&\rho_{cl}\cdot V_m\cdot\frac{\partial w_m(x,t)}{\partial t}=-L\cdot G_m\cdot\frac{\partial w_m(x,t)}{\partial x}+G_s(t),\\&c_a\cdot V_m\cdot\frac{\partial T_m(x,t)}{\partial t}=-L\cdot G_m\cdot c_{cl}\cdot\frac{\partial T_m(x,t)}{\partial x}+G_s(t)\cdot\left[r+c_s\cdot(T_s(t)-T_c)+c_w\cdot(T_c-T_m(t))\right],\end{aligned}\right\}\tag{1}$$

where c_{cl}, c_s, c_w are specific thermal capacity of clay, steam, water, respectively; r is a evaporation heat; V_m is the volume of ceramic mixture in the mixer; G_m – mixer rate; T_c – temperature of the steam condensation; ρ_{cl} –density of the clay; c_a – average volume specific heat of the mixer

The amount of heat, abstracted by steam and condensate while cooling, is significantly less than the amount of heat which is released during condensation, so we can abandon these components. Being restricted by the study of the process of mixing dynamics when the mixer is working in the mode of humidity and temperature stabilization, and considering the initial conditions to be zero, we apply Laplace transformation to equations systems (1). Here we obtain:

$$\left.\begin{aligned}&\rho_m\cdot V_m\cdot w_m(x,p)\cdot p=-L\cdot G_m\cdot\frac{dw_m(x,p)}{dx}+G_s(p);\\&c_a\cdot V_m\cdot T_m(x,p)\cdot p=-L\cdot G_m\cdot c_{cl}\cdot\frac{dT_m(x,p)}{dx}+G_s(p)\cdot r,\end{aligned}\right\}\tag{2}$$

where p is Laplace operator.

If you add extra water into the mixer, which is done in Section $x = 0$ of the system in question, a discrete change of humidity and temperature of the mixture occur in this section. The can be defined by expressions [12, 21]:

$$\left.\begin{aligned}&w_m(0,p)=\frac{G_m(p)\cdot w_{cl}(0,p)+G_w(0,p)}{G_m(p)+G_w(0,p)};\\&T_m(0,p)=\frac{G_m(p)\cdot c_{cl}\cdot T_{cl}(0,p)+G_w(0,p)\cdot c_w\cdot T_w}{G_m(p)\cdot c_{cl}+G_w(0,p)\cdot c_w}.\end{aligned}\right\}\tag{3}$$

Solution of the equations (2) with the boundary conditions (3) which are zero in initial conditions (in relation to the working point under consideration) make it possible to get operator expressions linking w_m and T_m with control and disturbance effects. In a special case, that is for Section $x=L$:

$$\left.\begin{aligned} w_m(L,p) &= e^{-\tau_1(p)\cdot p}\cdot w_m(0,p)+\frac{1-e^{-\tau_1(p)\cdot p}}{V_m\cdot\rho_m\cdot p}\cdot G_s(p); \\ T_m(L,p) &= e^{-\tau_2(p)\cdot p}\cdot T_m(0,p)+\frac{G_s(p)\cdot r\cdot(1-e^{-\tau_2(p)\cdot p})}{V_m\cdot c_a\cdot p}, \end{aligned}\right\} \quad (4)$$

where $\tau_1(p)$, $\tau_2(p)$ are delays with variable values as the depend on the performance of the installation

$$\tau_1(p)=\frac{V_m\cdot\rho_m}{G_m(p)} \quad (5)$$

$$\tau_2(p)=\frac{V_m\cdot c_a}{G_m(p)\cdot c_{cl}} \quad (6)$$

Analytical dependencies (4) – (6) made it possible to synthesize the structure shown on Figure 1. It is a mathematical model of the process of ceramic mixture preparation in the clay mixer of continuous action as a control object.

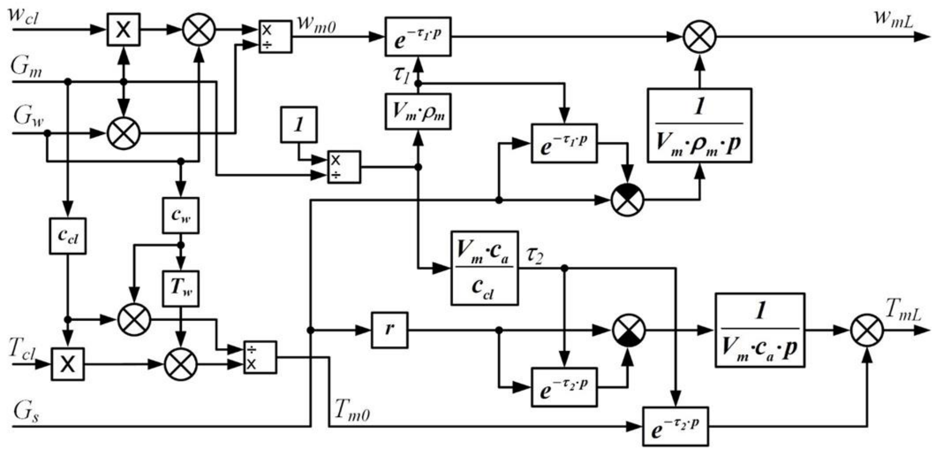

Figure 1. Mathematical model of the process of ceramic mixture preparation in clay mixer of continuous action as an object of control, where $w_{m0} = w_m(0,p)$; $T_{m0} = T_m(0,p)$; $w_{mL} = w_m(L,p)$; $T_{mL} = T_m(L,p)$

For parametric identification of the analyzed process as an object of control we use the method of computational experiments. Within the developed method and in accordance with a synthesized mathematical description, including structural diagram (see Figure 1) the authors used Matlab Simulink program software and created a computer model of the control object (see Figure 2).

As you can see, the developed mathematical description has a number of significant non-linearity. It is known that the mixer is a part of the multistage preparation of raw material, so its performance capacities should be coordinated with other installations performance. This leads to the fact that the model parameters are non-stationary. Let us consider this variation taking a clay mixer with $L = 2\ m$ length, working volume of $V_m = 0.53\ m^3$ and nominal performance $G_{m.n} = 13.5\ kg/sec$ as an example.

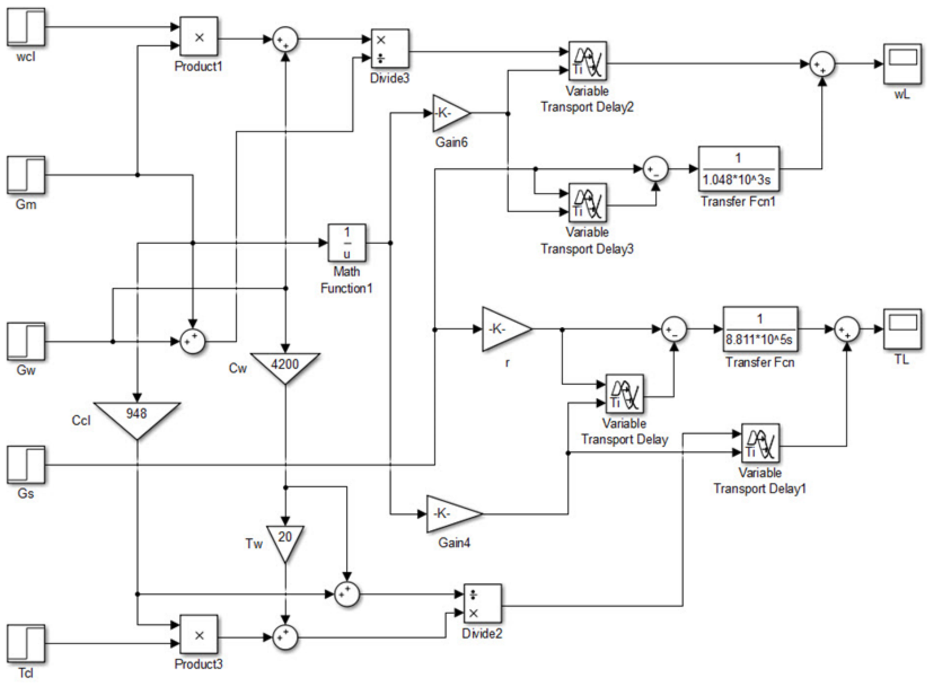

Figure 2. Computational model of the process of ceramic mixture preparation in clay mixer of continuous action as an object of control

The computational experiment was conducted according the following procedure. Let us set the following variables to their initial values $G_{s0} = 0.188\ kg/sec$, $G_{w0} = 0.8kg/sec$, $w_{cl0} = 0.14$, $T_{cl0} = 10°C$. Experiments were conducted with three modes of operation, when $G_{m01} = G_{m.n} = 13.5\ \ kg/sec$, $G_{m02} = 0.75\cdot G_{m.n} = 10.13\ kg/sec$ and $G_{m03} = 0.5\cdot G_{m.n} = 6.75\ kg/sec$. The experiment proved that after *150sec* of submitting input influences all processes "in the large" stopped. At the moment $t = 150\ sec$ value G_{s0} was changed stepwise for the value $\Delta G_{s1} = +0.019\ kg/sec$, with other parameters of the working point remaining unchanged. The transition process was registered. Then after returning to the working point value G_{s0} was changed stepwise for $\Delta G_{s2} = -0.019\ kg/sec$. Similarly, we studied the behavior of the object changing the flow rate of water first for the value $\Delta G_{w1} = +0.08\ kg/sec$, and then for $\Delta G_{w2} = -0.08\ kg/sec$.

3. Results

Research results shown in Table 1 demonstrate that when a clay mixer performance is changed, parameters of the process of preparation of ceramic mixture preparation vary. If a clay mixer performance is changed within $G_{m.n} \le G_m \le 0.5\cdot G_{m.n}$, there is also a change if transfer coefficients of the object, i.e. coefficient $k_{1w} = \frac{\Delta w_{mL}}{\Delta G_w}$ changes by 1.8 times, coefficient $k_{1T} = \frac{\Delta T_{mL}}{\Delta G_w}$ – by 1.5 times $k_{2w} = \frac{\Delta w_{mL}}{\Delta G_s}$ and $k_{2T} = \frac{\Delta T_{mL}}{\Delta G_s}$ by 2.4 times, parameters of the delay elements τ_1 и τ_2 change by 2 times.

This parameters variety should be taken into account in the future to achieve robust sustainability of synthesized automatic control systems of a clay mixer.

The obtained results show that mixing of ceramic mixture in a blade clay mixer of continuous motion takes place in a situation where it is necessary to adjust the capacity of the aggregate in the course of work, which causes variation in its performance. Therefore, this technological process can be referred to the objects of control with parametric uncertainty.

Table 1. Computational experiments and their results

Increment	G_{m01} = 13.5 kg/s			
	Transient response w_{mL}		Transient response T_{mL}	
	w_{L0} = 0.201		T_{L0} = 46.93 °C	
	Δw_L	τ_1, s	ΔT_L, °C	τ_2, s
ΔG_{s1} = +0.019 kg/s	$+12.8 \cdot 10^{-4}$	70.67	3.53	72.29
ΔG_{s1} = –0.019 kg/s	$-10.8 \cdot 10^{-4}$	70.67	–2.97	72.29
ΔG_{w1} = +0.08 kg/s	$+45.2 \cdot 10^{-4}$	70.67	0.16	72.29
ΔG_{w2} = –0.08 kg/s	$-45.7 \cdot 10^{-4}$	70.67	–0.17	72.29
	G_{m02} = 10.13 kg/s			
Increment	Transient response w_{mL}		Transient response T_{mL}	
	w_{L0} = 0.22		T_{L0} = 59.04 °C	
	Δw_L	τ_1, s	ΔT_L, °C	τ_2, s
ΔG_{s1} = +0.019 kg/s	$+17.5 \cdot 10^{-4}$	94.18	4.69	96.33
ΔG_{s1} = –0.019 kg/s	$-13.9 \cdot 10^{-4}$	94.18	–3.95	96.33
ΔG_{w1} = +0.08 kg/s	$+58.4 \cdot 10^{-4}$	94.18	0.19	96.33
ΔG_{w2} = –0.08 kg/s	$-58.3 \cdot 10^{-4}$	94.18	–0.2	96.33
	G_{m03} = 6.75 kg/sec			
Increment	Transient response w_{mL}		Transient response T_{mL}	
	w_{L0} = 0.257		T_{L0} = 83.18 °C	
	Δw_L	τ_1, s	ΔT_L, °C	τ_2, s
ΔG_{s1} = +0.019 kg/s	$+25.4 \cdot 10^{-4}$	141.3	7.04	144.6
ΔG_{s1} = –0.019 kg/s	$-21.8 \cdot 10^{-4}$	141.3	–5.94	144.6
ΔG_{w1} = +0.08 kg/s	$+80.4 \cdot 10^{-4}$	141.3	0.21	144.6
ΔG_{w2} = –0.08 kg/s	$-82.6 \cdot 10^{-4}$	141.3	–0.24	144.6

This situation is compounded by the fact that the work of the mixer goes together with wear and tear of its parts, a variation of physical and chemical properties of raw materials and parameters of the drive motor (assessment of the impact of these factors on the process of mixing will be done later). Efficient service of such an object is only possible with the use of control systems with the property of robustness, for example, multiloop systems with one measurment coordinate. Structural synthesis and parametric optimization of such systems present a complex task to be solved afterwards.

4. Conclusions

The paper demonstrates that the process of ceramic mixture preparation while solving problems of automation of building materials with given properties production represents a non-linear two-dimensional control object with distributed parameters which is to a great extent a non-stationary object.

On the basis of the proposed mathematical description and the structure the process of ceramic mixture preparation in a clay mixer as an object of control the researchers synthesized a computational model in Matlab Simulink program software. Humidity and temperature of the mixture were taken as output coordinates of the model. The obtained model made it possible to carry out a number of computational experiments and evaluate the magnitude of the parameters of the process of ceramic mixture preparation in a clay mixer as an object of control.

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