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MINIMIZATION OF MISMATCH IN METAL HOLDING IN REVERBATORY FURNACES

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A solution of the problem of minimization of the deviation of an actual thermal process from the desired one in metal holding in a reverbatory furnace is suggested.

We consider the problem of heat treatment of a thermally thin body in a reverbatory furnace. The dynamics of temperature variation of the metal ingot and heating medium is described by the equations [1]:

$$\frac{dT_{\text{h}}}{dt} = A_1 \nu - A_2 T_{\text{h}} - A_3 (T_{\text{h}} - T) , \tag{1}$$

$$\frac{dT}{dt} = \mu (T_{\text{h}} - T) \tag{2}$$

with the initial conditions

$$T_{\text{h}} (0) = T_{\text{h}0} , \quad T (0) = T_0 . \tag{3}$$

Let for the given thermal process the desired operating conditions of the heating device be given at $\nu =$ const.

We determine $T_{\text{h}}(t)$ and $T(t)$

$$T_{\text{h}} (t) = T_{\text{h.inhom}} (t) + T_{\text{h.hom}} (t) , \quad T (t) = T_{\text{inhom}} (t) + T_{\text{hom}} (t) ,$$

whence it follows that

$$T_{\text{h.inhom}} (t) = T_{\text{inhom}} (t) = \frac{A_1}{A_2} \nu , \quad T_{\text{hom}} (t) = C_1 \exp (k_1 t) + C_2 \exp (k_2 t) ,$$

$$T_{\text{h.hom}} (t) = C_1 \exp (k_1 t) + C_2 \exp (k_2 t) + \frac{1}{\mu} (C_1 k_1 \exp (k_1 t) + C_2 k_2 \exp (k_2 t)) ,$$

$$C_1 = \frac{(T_{\text{h}0} - T_0) \mu - T_0 k_2}{k_1 - k_2} , \quad C_2 = \frac{T_0 k_1 - (T_{\text{h}0} - T_0) \mu}{k_1 - k_2} ,$$

$$k_1 = \frac{1}{2} (- (A_2 + A_3 + \mu) + \sqrt{(A_2 + A_3 + \mu)^2 - 4 A_2 \mu}) ,$$

$$k_2 = \frac{1}{2} (- (A_2 + A_3 + \mu) - \sqrt{(A_2 + A_3 + \mu)^2 - 4 A_2 \mu}) .$$

But a real thermal process with temperatures T_{h}^* and T^* differs, as a rule, from the desired one

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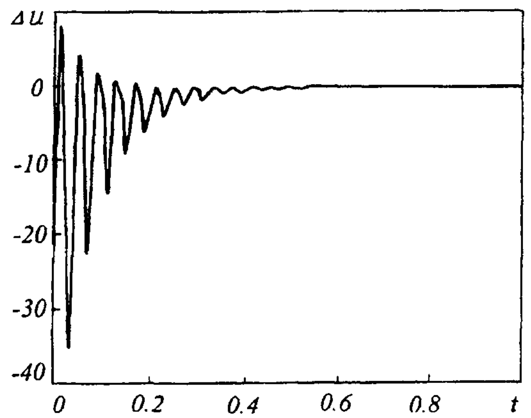

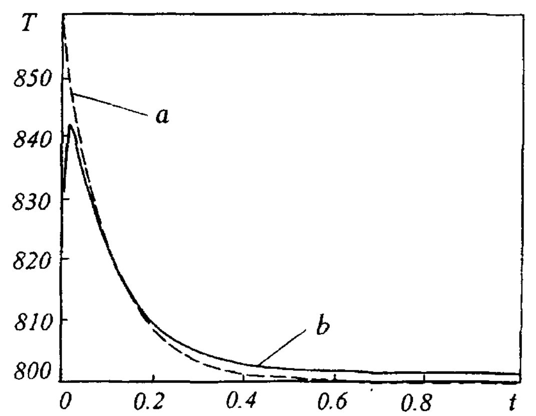

Fig. 1. Deviation of the actual flue flow rate from the desired one. Δu, m^3/h; t, h.

Fig. 2. Plots of time variation of temperatures of metal ingot (a) and heating medium (b). T, °C.

$$\frac{dT_h^*}{dt} = A_1 v^* - A_2 T_h^* - A_3 (T_h^* - T^*) , \quad \frac{dT^*}{dt} = \mu (T_h^* - T^*)$$

with the initial conditions not coinciding with (3):

$$T_h^* (0) = T_{h0}^* , \quad T^* (0) = T_0^* .$$

Therefore, we face the problem of minimization of the mismatch obtained for the gas ΔT_h, and metal ΔT temperatures and for the fuel flow rate Δv:

$$\frac{d\Delta T_h}{dt} = A_1 \Delta v - A_2 \Delta T_h - A_3 (\Delta T_h - \Delta T) , \quad \frac{d\Delta T}{dt} = \mu (\Delta T_h - \Delta T) ,$$

$$\Delta T_h (0) = \Delta T_{h0} , \quad \Delta T (0) = \Delta T_0 , \quad \int_0^{t_f} (\alpha \Delta T_h (t)^2 + \beta \Delta T (t)^2 + \gamma \Delta v (t)^2) \, dt \rightarrow \min ,$$

where $\Delta T_h = T_h - T^*$; $\Delta T = T - T^*$, $\Delta v = v - v^*$; $\Delta T_{h0} = T_{h0} - T_{h0}^*$, $\Delta T_0 = T_0 - T_0^*$.

Having replaced the variables and denoting

$$x = \begin{pmatrix} \Delta T_h \\ \Delta T \end{pmatrix} , \quad u = \Delta v , \quad A = \begin{pmatrix} A_2 + A_3 & - A_3 \\ - \mu & \mu \end{pmatrix} , \quad B = \begin{pmatrix} - A_1 \\ 0 \end{pmatrix} ,$$

$$x_f = \begin{pmatrix} \Delta T_{h0} \\ \Delta T_0 \end{pmatrix} , \quad P = \begin{pmatrix} \alpha & 0 \\ 0 & \beta \end{pmatrix} , \quad Q = \gamma ,$$

we pass to a problem of the form

$$\frac{dx}{dt} = Ax + Bu , \tag{4}$$

$$x (t_f) = x_f , \tag{5}$$

$$I (u) = \int_0^{t_f} (x^T P x + u^T Q u) \, dt \rightarrow \min_{u \in R} . \tag{6}$$

Thus, in holding of a metal ingot in a furnace with a fixed temperature it is necessary to solve the problem of constructing a regulator of heating to the holding temperature if the temperatures of the ingot and of the heating medium deviate from the prescribed ones.

A method of solving the problem of analytical design of optimum regulators (4)-(6) is considered in [2].

The software in the system Matlab 5.1 was developed for implementation of such a procedure.

Calculation was made at the following initial data: the initial deviations of the furnace and metal ingot temperatures were, respectively. $\Delta T_{h0} = 30^{\circ}C$, $\Delta T_0 = 60^{\circ}C$, the holding temperature was $800^{\circ}C$, $A_1 = 6.11\ h^{-1}$, $A_2 = 0.638^{\circ}C/m^3$, $A_3 = 3.45\ h^{-1}$, $\mu = 0.69\ h^{-1}$, $\alpha = \beta = \gamma = 1$, $t_f = 1$ h.

The deviation of the actual flow rate of fuel in an optimum heating process from the desired one at the prescribed holding temperature of the metal ingot and a graph of the optimum operating conditions of the furnace are depicted in Figs. 1 and 2, respectively.

NOTATION

$T_h(t)$, temperature of heating medium, $^{\circ}C$; $T(t)$, temperature of metal ingot, $^{\circ}C$; v, gas flow rate, m^3/h; t_f, finite holding time, h; A_1, A_2, A_3, μ, constants characterizing the dynamics of metal ingot heating; α, β, γ, weight coefficients larger than zero. Subscripts: f, finite; hom, homogeneous; inhom, inhomogeneous; T, transposing.

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