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POSSIBILITIES OF THERMAL SYSTEMS CONTROL

MOŽNOSTI ŘÍZENÍ TEPELNÝCH SYSTÉMŮ

Abstract

This contribution describes different approaches to thermal system control. Not only PID control but also sliding mode controls were used. In addition the different modifications of sliding mode control were used, such as extension with integral element or continuous substitution of sign function. Considering the thermal system allows applying cooling element, the control algorithm using cooling and heating parts was tested too. All designed algorithms were verified with help of computer simulation and also directly on laboratory stand. All used control algorithms ensured required temperature but with different control quality.

Abstrakt

Příspěvek popisuje různé přístupy k řízení tepelných systémů. Kromě klasické PID regulace byly použity algoritmy řízení pracující v klouzavém režimu. Také byly použity další modifikace klouzavého řízení a to jak rozšíření o integrační složku, tak i spojitá náhrada znaménkové funkce. Vzhledem k tomu, že použitý tepelný systémy může používat i chlazení, bylo vyzkoušeno i řízení kombinující jak zahřívání, tak i chlazení. Všechny navržené algoritmy řízení byly ověřeny pomocí číslicové simulace i přímo na laboratorním zařízení. Všechny použité algoritmy dosáhly žádané teploty, avšak s rozdílnou kvalitou řízení.

1 INTRODUCTION

The hot-air aggregate enables using not only one dimensional control tasks (temperature or flow air control), but also two dimensional control tasks (control of temperature and flow air at once). The laboratory stand consists of a lamp (heating and light source) which is situated in tunnel. Through tunnel fan blows air flow. The lamp and fan are fed by controlled voltage supply. The structure of laboratory stand is shown on Fig. 1.

For the temperature measurement there are three sensors situated in tunnel: Thermistor T1 is located on the bulb; second thermistor is at a distance 5 millimetres from the bulb and the last one thermistor 3 is at a distance 15 millimetres from bulb. Further there is flow-meter for determination the air flow in the tunnel. [SMUTNÝ L., ŠKUTA J., BABIUCH, M. & WAGNEROVÁ R. 2006].

The laboratory stand is connected to the computer with microcomputer unit CTRL v3 and use RS232 protocol. This unit enables to connect laboratory stand with 4 analog inputs, 2 analog output, 4 logic inputs and outputs. The control algorithms were realized in Matlab environment.

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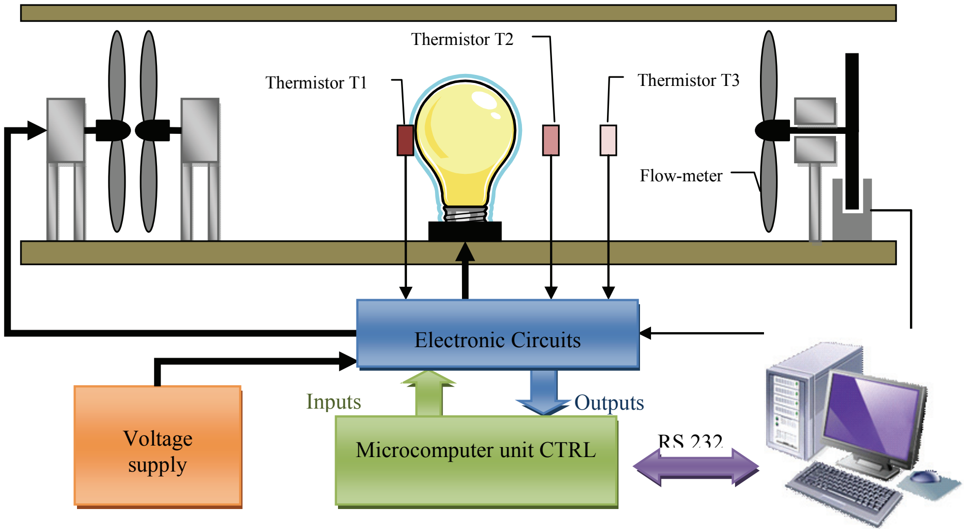

Fig. 1 The structure of laboratory stand hot-air aggregate

2 SLIDING MODE CONTROL DESIGN

The quality of close control systems without knowledge of mathematical model or measurable disturbances can be ensured by using sliding mode control. Sliding mode control means discontinuous control, where according to value switching function control has marginal value [YOUNG, D.K., UTKIN, V.I. & ÖZGÜNER, Ü. 1999], [WAGNEROVÁ, R. 2008]. The control is written by equation

$$\boldsymbol{u}^{sl} = \left[u_1^{sl}, u_2^{sl}, \ldots, u_m^{sl}\right]^T \tag{1}$$

$$u_j^{sl} = \begin{cases} u_j^+ & \text{for} \quad m_j > 0 \\ u_j^- & \text{for} \quad m_j < 0 \end{cases} \tag{2}$$

where:

u_j^+, u_j^- - marginal value of control,

m_j – element of switching function.

The form of switching function m_j can come out from state variables aggregation method [VÍTEČEK, A. & VÍTEČKOVÁ, M. 2002]. Then it is describes

$$\boldsymbol{u}^{sl} = \boldsymbol{U}^m \mathbf{sgn}(\boldsymbol{m}) \tag{3}$$

$$\boldsymbol{m} = \boldsymbol{D}(\boldsymbol{e} - \boldsymbol{e}_0) + \boldsymbol{T}^{-1}\boldsymbol{D}\int_0^t \boldsymbol{e}\, d\tau \tag{4}$$

$$\boldsymbol{U}^m = \mathrm{diag}\left[u_1^m, u_2^m, \ldots, u_m^m\right] \tag{5}$$

$$\mathbf{sgn}(\boldsymbol{m}) = \left[\mathrm{sgn}(m_1), \mathrm{sgn}(m_2), \ldots, \mathrm{sgn}(m_m)\right]^T \tag{6}$$

where:

$\boldsymbol{U}^m$ - diagonal matrix, whose elements u_j^m are marginal values of control variables, sgn – sign function.

Sliding mode control is discontinuous, robust and simple, but its disadvantage is control high activities; it means quick switching between marginal values. It can be removed by using continuous approximation of sign function instead of sign function.

Another possibility is extending discontinuous sliding control of integral element. The property of integration element is decreasing higher frequency which can be see on integration calculation of harmonic function

$$\int \sin(\omega)t dt = -\frac{1}{\omega}\cos(\omega t) \tag{7}$$

It is equivalent for cosine function.

The most simple possibility of sliding mode control with integration element will be supposed, it means the linear combination of two expression, so that the control algorithm is described by equation

$$\boldsymbol{u}^{sl} = \boldsymbol{U}^{m}\mathbf{sgn}(\boldsymbol{m}) + \boldsymbol{K}\int_0^t \boldsymbol{m} d\tau \tag{8}$$

where:

$\boldsymbol{K}$, $\boldsymbol{U^m}$ – diagonal matrices with constant elements and dimension m.

The second modification of sliding mode is using integral element in multiplication form, in that case the control algorithm is described by equation

$$\boldsymbol{u}^{sl} = \boldsymbol{U}^{m}\mathbf{sgn}(\boldsymbol{m}) * \boldsymbol{K}\int_0^t \boldsymbol{m} d\tau \tag{9}$$

The switching function has the same form as in (4), elements of matrix $\boldsymbol{K}$ have same value and sign as element of matrix $\boldsymbol{U^m}$ otherwise the control algorithm will be unstable.

3 THE TEMPERATURE CONTROL

The sliding mode control and its modifications were used for temperature control of hot-air aggregate. The mathematical model of stand was determined by methods of experimental identification. As the robust control algorithms are used exact knowledge of mathematical model is not necessary. The system order and measurable errors are required.

3.1 The designed control algorithms

From experimental identification it was found out that hot-air aggregate is second order nonlinear system that is why the aggregation matrix $\boldsymbol{D}$ and matrix of time constants $\boldsymbol{T}$ have presentation

$$\boldsymbol{D} = \boldsymbol{d}^T = \begin{bmatrix} \frac{1}{T_1} & 1 \end{bmatrix}, \boldsymbol{T} = T_1 \tag{10}$$

where:

T_1 – time constants choosing according to the required closed-loop system behavior (marginal aperiodic system).

The switching function is described by equation

$$m = \left[\frac{1}{T_1^2}\int_0^t e_1 d\tau + \frac{2}{T_1}(e_1 - e_{10}) + e_2 \right] \tag{11}$$

where:

e_1 – difference between required and real temperature,

$e_2 = \dot{e}_1$.

The sliding mode control and its modifications have following presentation

$$u^{sl} = u^m \operatorname{sgn}(m) \tag{12}$$

$$u^{tgh} = u^m \operatorname{tgh}(\theta m) \tag{13}$$

$$u^{sl} = u^m \operatorname{sgn}(m) + k\int_0^t m d\tau \tag{14}$$

$$u^{sl} = u^m \operatorname{sgn}(m) * k\int_0^t m d\tau \tag{15}$$

The last modification of sliding mode control is combination of heating and cooling process. According value of switching function fan or lamp is running. In that case the control algorithm is written by equations

$$u^{sl} = u^{mh} \operatorname{sgn}(m) \quad \text{for} \quad m \geq 0 \tag{16}$$

$$u^{sl} = u^{mc} \operatorname{sgn}(m) \quad \text{for} \quad m < 0 \tag{17}$$

where:

u^{mh} - marginal value of control variable for heating,

u^{mc} - marginal value of control variable for cooling.

3.2 The verification of designed control algorithms

The designed control algorithms were verified by computer simulation using simulation program MATLAB/SIMULINK and also directly on laboratory stand. The courses of temperature and used controls are shown on Fig. 2 – 6. On all figures it can be see courses of three variables: variable **w** is required temperature, variable **y** is real temperature, and variable **u** is control. [RICHTR, L. 2009]

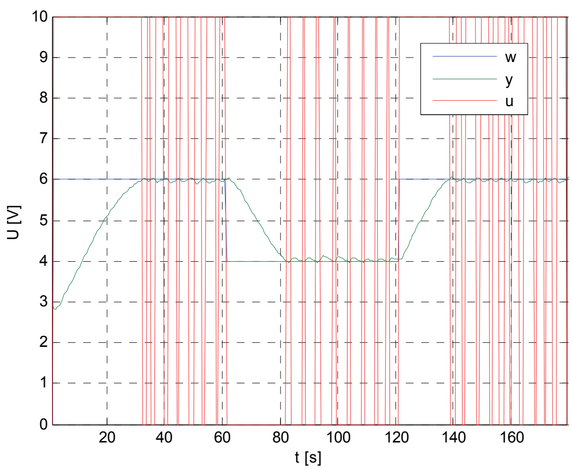

Fig. 2 The time responses of temperature and control for algorithm (12)

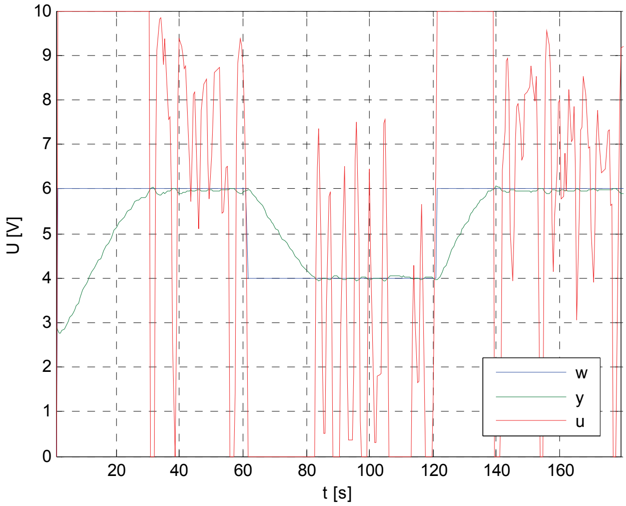

Fig. 3 The time responses of temperature and control for algorithm (13)

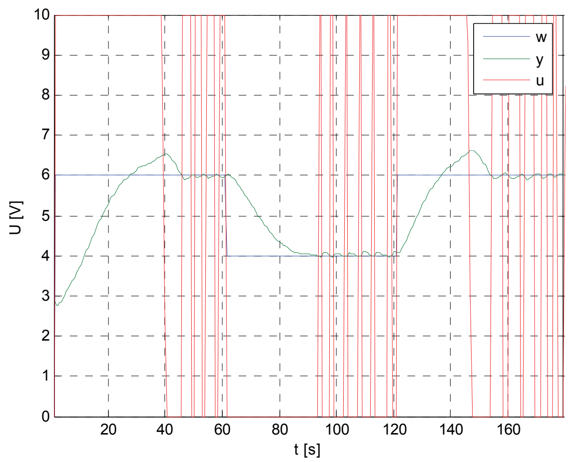

Fig. 4 The time responses of temperature and control for algorithm (14)

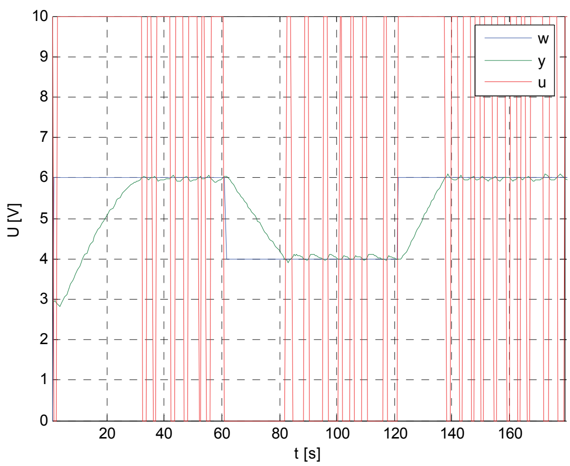

Fig. 5 The time responses of temperature and control for algorithm (15)

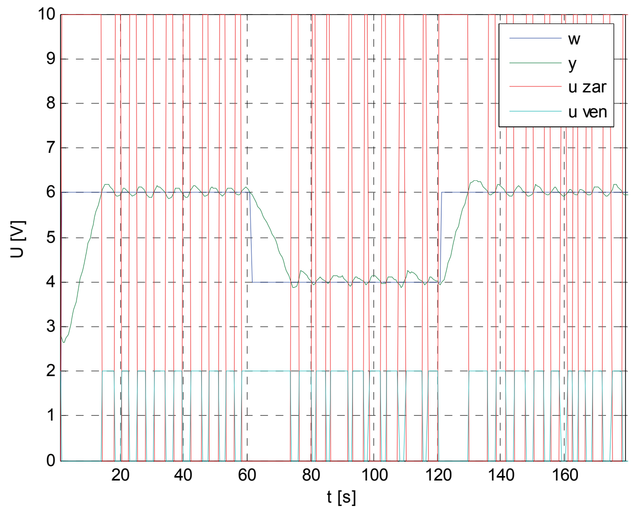

Fig. 6 The time responses of temperature and control for algorithm (16), (17)
u zar – heating, u ven - cooling

4 CONCLUSIONS

The contribution presents possibilities of temperature control of hot-air aggregate. There are described properties of sliding mode control: discontinuous, its extension with integral element or with continuous substitution of sign functions. The all described algorithms were used to temperature control and ensured reaching the required value.

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