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Sliding Mode Indicator Model's at Thermal Control System for Furnace

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Abstract: This paper discusses and deals the development of the Sliding Mode Control Indicator with the using technique of Discontinuous Control for furnace in Laser Physics. To improve efficiency of practical implementation, the furnace control system is regarded as electronic elements having a discontinuity-switching mode where the sliding modes are the basic motions. Implementation of this approach implies the knowledge of the conditions of the occurrence of sliding mode, for which purpose a sliding mode indicator hardware and model has been developed by means the LabView graphical programming language under Windows environment

1. INTRODUCTION

Furnace control in laser physics can be difficult, due to their intrinsic nonlinearity. In fact, control should ensure system stability in any operating condition and good static and dynamic performances in terms of rejection of input voltage disturbances and effects of load changes (output impendence). These characteristics, of course, should be maintained in spite of large input voltage, output current, and even parameter variations (robustness).

Control within sliding mode (SM) enables us to decrease the sensitivity to variations of chip characteristics making them independent upon the environment. These features make this control technique a valid alternative to standard control approaches like current-mode control.

The block-diagram of control system with Indicator of Sliding Mode is shown on Figure 1, where $e(t)$ - is the error of control signal (Mkrttchian, 2007).

From the point of view of mathematics, the problem may be reduced to that of finding the area of attraction to the manifold of the discontinuity surfaces intersection.

In the described algorithm, a new component called Sliding Mode Indicator is proposed. This block detects the occurrence of SM in the system. If the SM does not occur, the indicator block deliberately generates the SM in the system (Mkrttchian, 1999-2007). Unfortunately by use this design result for chip design needs some development process and design new Indicator diagram. Control within sliding mode enables us to decrease the sensitivity to variations of chip characteristics making them independent upon the environment. The mentioned problems can be overcome by using asymptotic observers of state and anticipatory devices eliminating delays. Discontinuity of control results in a discontinuity of the right-hand parts of the differential equations describing the system's dynamic properties. Deliberate introduction of objects into the sliding-mode operation will necessitate a continuous monitoring of the sliding-mode occurrence and stability (Utkin, 1982).

Our purpose is to achieve a model suitable for the use with all types of solution simulation. Therefore it should be presented as a simple equivalent circuit. The circuit elements are derived from physical concepts, which are more often than not lost whenever a complex model for a solution is extracted from an optimization model. For the Finite Difference Time Domain computation of the object ports are defined on the coaxial lines as it is used in most simulators by observing wave ratios. The ports for solution's equivalent circuit are concentrated or internal ports defined by voltage and current.

The resulting S-parameters of the ports are used to extract equivalent circuit elements leading to well defined values with physical senses. The essential components of the solution model are the sliding-mode indicator, observer and the anticipatory device.

As already noted, the approach used is oriented toward a deliberate introduction of sliding modes over the intersection of surfaces on which the control vector components undergo discontinuity. Realization of such an approach implies the knowledge of the conditions of the occurrence of sliding mode. Designed for this purpose was the indicator of sliding

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modes. From the point of view of mathematics, the problem may be reduced to that of finding the area of attraction to the manifold of the discontinuity surfaces intersection (Dubrovsky and Kortnev, 1968). On the indicator input, two signals x and g from the equivalent circuit are supplied.

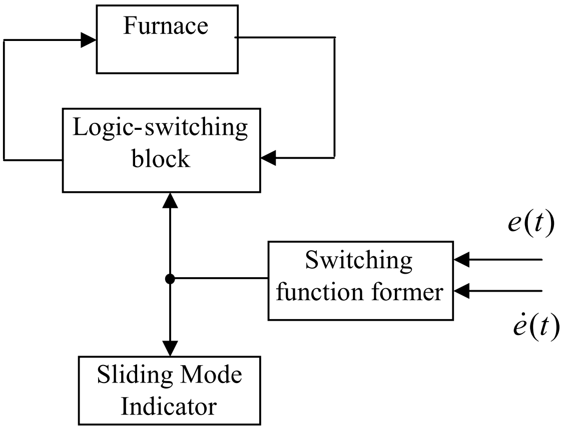

Fig. 1. Block-diagram of control system with Indicator of Sliding Mode

The indicator compares two signals recording the moment of changing the signs of function $e(t)$ and $g(t)$, see (1).

$$g(t) = C_1 e(t) + C_2\, de/dt \qquad (1)$$

where $g(t)$ - is function of indicator; $e(t)$ - is the error signal.
In (1) C_1 and C_2 is constant of object control; g is function of switching; x is system parameter, t is time.

The rule of changing of control function is

$$U(t) = \begin{cases} K_1 ...if...g(t)e(t) > 0 \\ K_2 ..if...g(t)e(t) < 0 \end{cases} \qquad (2)$$

where $K_1 > 0, K_2 < 0$ - fixed parameters of regulator;

The goal is to find the coefficients for a switching equation of a first order lag temperature system and the associated temperature system. The temperature sensor should be placed so it responds to changes in the actual temperature as quickly as possible. This reduces the sensor time constant. In a perfect world there would be no difference between the actual and measured temperature. In this case one could simply switch on and off the heater at the set point. In the real world there is a lag in the sensor response. If one were to switch the output using the measured temperature without taking into account the sensor lag, the actual temperature would oscillate around the set point. To compensate for the sensor lag we must take into account sensor time constant

2. DEVELOPMENT OF SLIDING MODE INDICATOR

The designed algorithm of sliding mode indicator based on Lab View programming is shown in Fig.2.

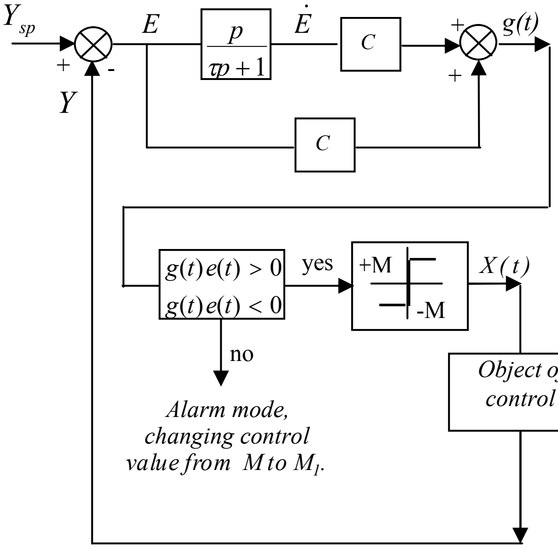

Fig. 2. Algorithm of development sliding mode indicator

3. DEVELOPMENT OF CONSTRUCTION PROCESS OF SM EXISTENCE REGION'S

As it known, the motion of the system operating in the sliding surface is invariant to disturbances, parameter uncertainties, coupling between channels, and nonlinearities seen in the system. The constant coefficients *Ci* of the sliding surface boundary described by (Mkrttchian, 1999-2007) are chosen to provide the output tracking motion in sliding mode. This is accomplished through construction of SM existence region and choosing the coefficients *Ci* from the region.
The graphic development method of construction of SM existence region is given on Figure 3.

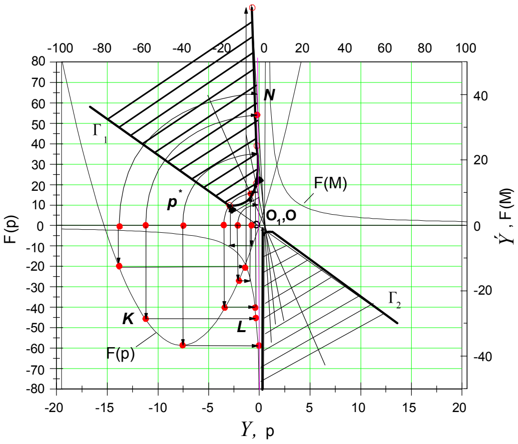

Fig. 3. The development SM existence region for furnace control system

The output signals of Sliding mode indicator are shown on Figure 2. In case of (a) the sliding mode occur in system; in case of (b) the system is out of sliding mode region; in case of (c) the system is deliberately introduced on sliding mode by changing of control value from M to M_1.

4. SYSTEM MODELING WITH SLIDING MODE

The goal is to find the coefficients for a switching equation of a first order lag temperature system and the associated temperature system. The temperature sensor should be placed so it responds to changes in the actual temperature as quickly as possible. This reduces the sensor time constant. In a perfect world there would be no difference between the actual and measured temperature. In this case one could simply switch on and off the heater at the set point. In the real world there is a lag in the sensor response. If one were to switch the output using the measured temperature without taking into account the sensor lag, the actual temperature would oscillate around the set point. To compensate for the sensor lag we must take into account sensor time constant and estimate how fast the error between the set point and measured temperature changing. This results in the sliding mode equation given below with e being the error between the set point and the measured temperature. If $s>0$ then the heater is turned on otherwise the heater is turned off.

$$s(t) = \tau_s \cdot \dot{e}(t) + e(t)$$

The following parameters of the plant were considered:

$G = 3.69$	Plant gain in degrees per % control
$\tau_p = 3.41$	Plant time constant in minutes
$\tau_s = 1$	Sensor time constant in minutes
$T = 1/60$	Update period in minutes. Update more often for less ripple in the PV.
$T_a = 25$	Ambient temperature.

Coefficients for the simulator are as follows.

$$A_p = \exp\left(\frac{-T}{\tau_p}\right) \qquad A_p = 0.995$$

$$B_p = (1 - A_p) \qquad B_p = 4.876 * 10^{-3}$$

$$A_s = \exp\left(\frac{-T}{\tau_s}\right) \qquad A_s = 0.983$$

$$B_s = 1 - A_s \qquad B_s = 0.017$$

Now convert the SMC equation to a form that can be used by a computer.

$\dot{e}$ is roughly equal to *(e[n]-e[n-1])/T.* The resulting equation is:

$$s = \tau_s \frac{e_n - e_{n-1}}{T} + e_n$$

Ignoring scale, this simplifies to:

$$s = \frac{\tau_s + T}{\tau_s} * e_n - e_{n-1}.$$

Letting $C = \dfrac{\tau_s + T}{\tau_s}$ the equation simplifies to

$$s = C * e[n] - e[n-1].$$

and we have $C = 1{,}017$.

5. SIMULATION USING A SYSTEM OF DIFFERENCE EQUATIONS

The first equation calculates the actual temperature. Notice that it uses the control output from the iteration before. The second equation calculates the measured temperature using the sensor time constant. The ambient temperature is taken into account so the temperature can decay down to the ambient temperature and not 0. The third equation just calculates the error. The fourth equation is the equation that does the sliding mode control. Notice that the control output is either fully on (100%) or off. There is no in between.

$$\begin{pmatrix} x_n \\ y_n \\ e_n \\ u_n \end{pmatrix} = \begin{bmatrix} A_p(x_{n-1} - T_a) + T_a + G * B_p * u_{n-1} \\ A_s(y_{n-1} - T_a) + T_a + B_s(x_n - T_a) \\ r_n - y_n \\ \left| \begin{matrix} 100 \ldots if \ldots (C * e_n - e_{n-1}) > 0 \\ 0 \ldots otherwise \end{matrix} \right. \end{bmatrix},$$

where x - is actual temperature in the plant difference equation;

y - is the measured temperature in the sensor difference equation;

e_n – error signal, Error = SP- PV;

Sliding Mode Control.

$s = \tau_s * e' + e$. If s>0, then turn on the heater else turn it off.

4. EXPERIMENTAL RESULTS

The control system includes: oven with a heater and a thermocouple; an amplifier that has sufficient gain (k=100) so as to provide the range of voltage needed; the PC hardware; voltage-controlled power supply for the oven heater. Software support is provided by the designed controller program written in the LabView programming language environment.

The DAQ board measures output from the operational amplifier. The voltage from the PC hardware is the control signal that will turn ON or OFF the heating element to keep temperature set programmatically and maintain the sliding mode. The model arrangement including the oven used in real experiment was allowed to achieve stability of ~0.5 ^{0}C.

5. CONCLUSIONS

This paper formulates using the methods of sliding mode control. The Sliding Mode Indicator is designed based on results obtained in the sphere of discontinuous system design.

The experimental results of applying the designed Sliding Mode Indicator illustrated the improvement of the achieved performance applied to the furnace control system design application in Laser Physics.

An additional component of the sliding mode control system – the sliding mode indicator – is proposed in the paper. The SM indicator allows for monitoring the existence of SM in the system and enforcing the SM via modification of the parameters if the SM fails. The application of the sliding mode indicator is demonstrated on the control system for furnace in laser physics.

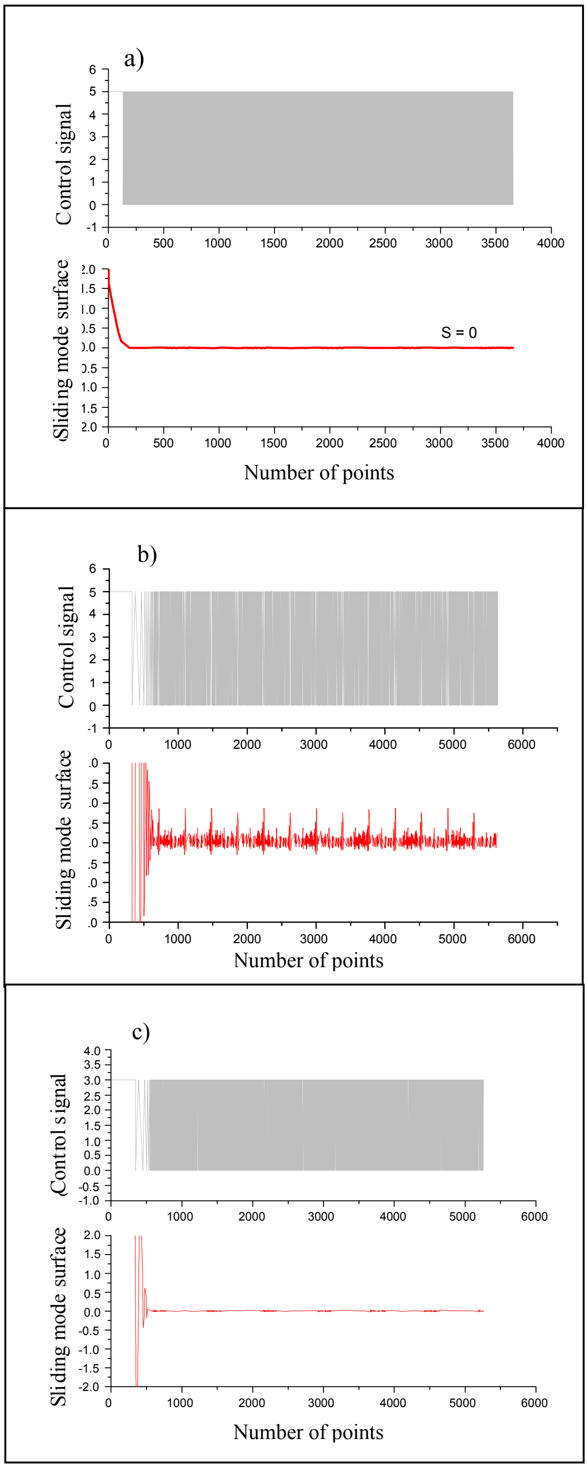

Fig. 4. The output signal of development SM Indicator

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