Temperature Profile Tracking Control with Memristor Based PI Controller in the Heat Flow System

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ABSTRACT : *In this study, a memristor based PI controller was designed and the performance of the controller was tested in simulation model on the heat flow system. Furthermore, the use of Memristor, which has an increasing interest in recent years, has been tested in the field of control systems. The simulation results show that the designed controller successfully performs reference temperature profile tracking.*

KEYWORDS -*Temperature Profile Tracking Control, Heat Flow, Memristor*

I.INTRODUCTION

Temperature control is extremely important in industrial and engineering applications [1-4]. Particularly in the industrial process, the control of the ambient temperature and the temperature control of the heat treatment of the materials are carried out by different control methods. The most common control tasks in temperature control applications are temperature setpoint control, temperature uniformity control, and temperature reference tracking control. Temperature profile tracking is used to achieve time-varying temperatures in the precision heat treatment of materials. Temperature profile tracking control is impressive due to the various problems of control theory in the real systems. It requires flexible, stable and adaptive control beyond factors such as the test environment and changing time constants.

Memristors, proposed by L. Chua in 1971 as missing circuit elements, have found wide application area in circuit designs after their physical realization in 2008 [5-8].

The proportional integral (PI) controller structure, which is superior in terms of resetting the steady state error that will occur in the system, has been preferred in many industrial applications [9-13]. On the other hand, PI controllers in different structures have been proposed by the researchers in order to increase the performance of the controller and eliminate the disadvantages such as delay in system response [14-17].

In this study, a memristor based PI controller (Mem-PI) design is presented using a Memristor which has been of increasing interest in recent years. The performance of the designed controller was tested for temperature profile tracking on the simulation model of Quanser's Heat Flow Experimental (HFE) setup. Simulation results are presented to demonstrate the success of the designed controller.

II.HEAT FLOW EXPERIMENTAL (HFE) SETUP

In the heat flow system shown in Fig. 1; the heated air mass is transported with the aid of a fan through the channel. Inside the channel are located in fixed distances three temperature sensors. The scheme with periodic reference variable is then designed and optimized for a stable behavior. A periodic reference variable that is physically possible by the model can be controlled using a Repetitive Control plugins with time delay of the route [18].

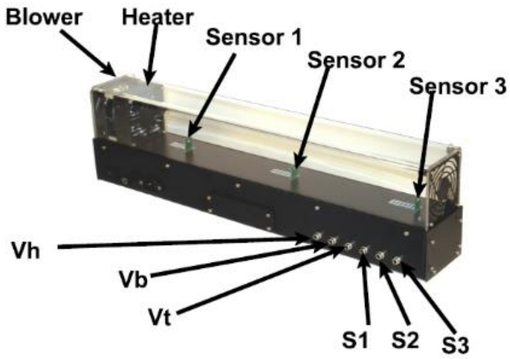

Figure 1. *Heat flow experimental (HFE) setup of QUANSER [18]*

Thermodynamic model of a system is difficult to express exactly. In practice, state variables of the system can be expressed as follows.

$$\dot{T} = F(V_h, V_b, T_a, x_n) \qquad (1)$$

where x_n is the distance between the n th sensor and the heater, V_b is blower voltage, V_h is heater voltage, T_a is ambient temperature and T_n is n th sensor temperature. The system model can be expressed as follows;

$$\dot{T} = f(T,t) + b(T,t)\ , T(t_0) = T_0 \qquad (2)$$

where T is the system state and $T(t_0)=T_0$ is the initial value of T. $u(t) \in \mathrm{R}$ is the control input and $f(T,t) \in \mathrm{R}$ is a bounded nonlinear vector function of the state vector that represents the nonlinear deriving terms. $b(T,t) \in \mathrm{R}$ is a bounded positive definite nonlinear function over entire state space. When uncertainties occur, functions $f(T,t)$ and $b(T,t)$ are of the form as follows;

$$f(T,t) = \hat{f}(T,t) + \Delta f(T,t) \qquad (3)$$

$$b(T,t) = \hat{b}(T,t) + \Delta b(T,t) \qquad (4)$$

where $\hat{f}(T,t)$ and $\hat{b}(T,t)$ are the known parts, Δf and Δb are the unknown parts of $\Delta f(T,t)$ and $\Delta b(T,t)$ in (2), respectively. In this way Eq. (2) can be written as fallow,

$$\dot{T} = \left(\hat{f} + \Delta f\right) + \left(\hat{b} + \Delta b\right)u(t) + d(t) \qquad (5)$$

where $d(t) \in R$ is the bounded external disturbances. Eq. (5) can be written as;

$$\dot{T} = \hat{f} + \hat{b}u(t) + (\Delta f + \Delta b u(t) + d(t)) \qquad (6)$$

III.MEMRISTORS

Memristor was introduced by Professor Leon Chua in 1971 [6]. And then it was produced in 2008 by HP researchers [7]. The relationship between the current and voltage of the memristor can generally be expressed as follows;

$$V(t) = R(t)i(t) = \frac{d\varphi}{dQ}i(t) \qquad (7)$$

Where, φ and Q denote the flux and charge respectively. The memristor resistance, termed memristance, is expressed as the ratio of flux to charge. The relationship between current and voltage proposed by HP research group for TiO_2 memristor,

$$V(t) = \left[R_{ON}\frac{x(t)}{D} + R_{OFF}\left(1 - \frac{x(t)}{D}\right)\right]i(t) \qquad (8)$$

Here, R_{OFF} and R_{ON} are high and low resistance states respectively. D and x denote the thickness of TiO_2 memristor and the doped area, respectively. The resistance value directly depends on the change of the x value and defined as,

$$\frac{dx(t)}{dt} = \mu_v \frac{R_{ON}}{D} i(t) \qquad (9)$$

Here, μ_v is the mobility of memristor and also the memristors exhibit a stuck hysteresis voltage-current relationship when sinusoidal signal is applied, and non-linearity decreases with increasing frequency such as Fig. 2.

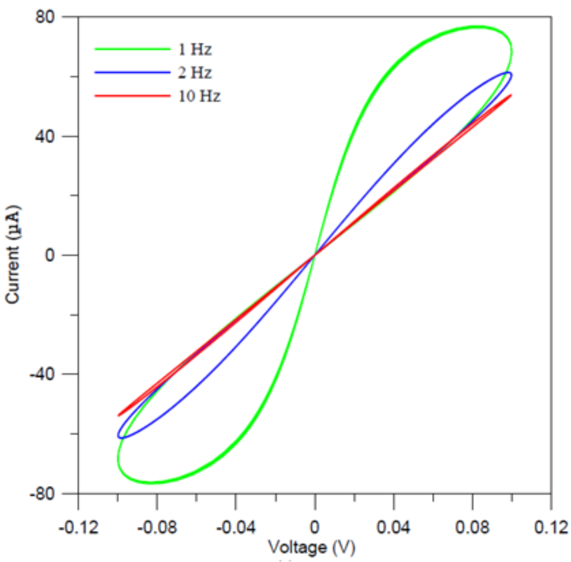

Figure 2. *The memristor current-voltage relationship with various frequencies [8]*

IV. CONTROLLER DESIGN

If T is the current temperature and T_d is the desired temperature value, the temperature profile tracking error for the controller design can be defined as follows.

$$e = T - T_d \tag{10}$$

The PI controller designed using op-amp is shown in Fig. 3. The capacitor in the circuit is used to store charge and represents the integral of the input. In the PI controller circuit, the output *u(t)* can be written as below;

$$u(t) = -\frac{R_2}{R_1}e(t) - \frac{1}{R_1 C}\int_0^t e(\tau)d\tau \tag{11}$$

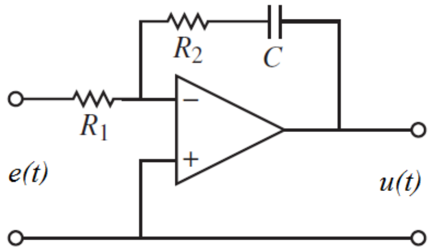

Figure 3. *Schematic diagram for PI controller using operational amplifier*

The main idea of the Mem-PI controller is to replace the resistor *R1* with a memristor as described in Fig. 4.

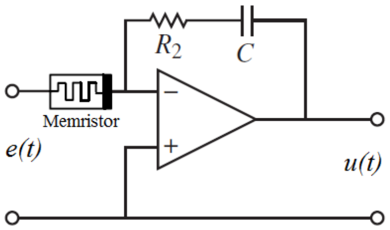

Figure 4. *The Mem-PI controller circuit*

If the control signal *u(t)* in the circuit given in Fig. 4 is rewritten using (8) and (11);

$$u(t) = -\frac{R_2}{\left[R_{ON}\frac{x(t)}{D} + R_{OFF}\left(1 - \frac{x(t)}{D}\right)\right]}e(t) - \frac{1}{\left[R_{ON}\frac{x(t)}{D} + R_{OFF}\left(1 - \frac{x(t)}{D}\right)\right]C}\int_0^t e(\tau)d\tau \tag{12}$$

The block diagram of the temperature profile tracking control of the HFE with the memristor based PI control (Mem-PI) approach is given in Fig. 5.

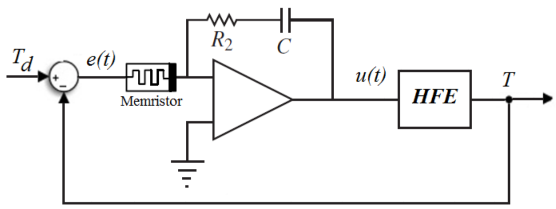

Figure 5. *Temperature control of the HFE using Mem-PI controller*

V. SIMULATION

In this section, a reference sign containing sudden changes and soft changes was applied to the simulation model of the heat flow experimental system. The reference signal was selected to start with a constant value and then continue with a sinusoidal signal. The results of the simulation study are given in Fig. 6 and Fig. 7. Fig. 6 shows the reference signal and simulation result, and Fig. 7 shows the control signal of the Mem-PI controller. The controller has reached 35 degrees Celsius, the initial value of the reference, in about 1.5 seconds. The error in the fixed part of the reference and the parts with soft change is less than about 1%.

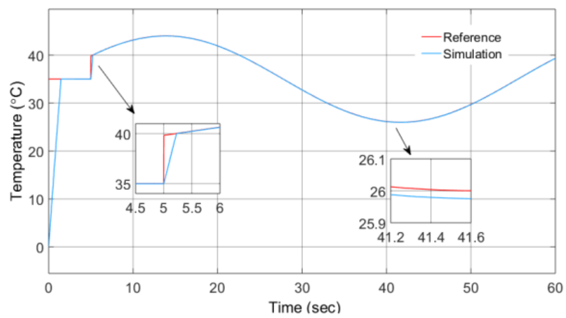

Figure 6. *Simulation result of Temperature profile control of the HFE using Mem-PI controller*

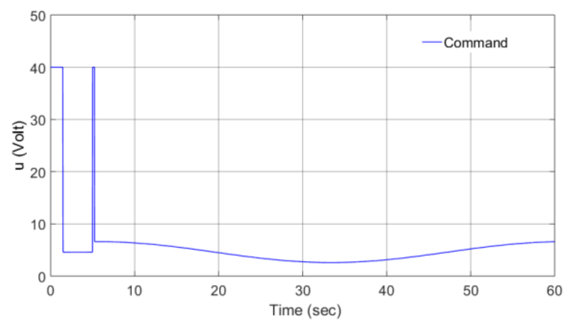

Figure 7. *Command signal of Mem-PI controller*

VI. CONCLUSION

In this study, a new memristor based PI controller was proposed. The control structure was obtained by using a memistor instead of gain resistance in the conventional PI controller circuit. The simulation results showed the success of the controller. In the future work, this controller is planned to be tested out on real-time experimental setup.

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