A Method of Model Reference Adaptive Fuzzy Controller for the Object of Temperature of Resistance Furnace with Changeable Parameters

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Abstract — *In reality, the control of objects with delay and parameters changed during the process as resistance furnace are often difficult to achieve the desired quality using only conventional controllers. This paper proposes a method of synthesizing a parallel model reference fuzzy adaptive controller, which uses an adaptive mechanism for the purpose of calibrating the output amplifier parameter and the integral factor input of the controller is suitable for changing the parameter of the object during operation. The control algorithm is verified through simulation results on Matlab Simulink for heating object is alternative thermal resistance with changeable parameters.*

Keywords — *fuzzy control, adaptive control, model reference.*

I. PROBLEM STATEMENT

In the current production lines, temperature is involved in many technological processes such as plastic industry, metallurgy, rubber, food ... In the industry, the temperature is mainly heated from such devices as resistance furnaces, arc furnaces ... They are the inertial control objects that are delay and have a changeable operation [1], [2]. In that case, the classical controller cannot satisfy the proposed quality requirements, so we need to study modern control methods to control them [3], [5]. One of the methods that the author proposes is to apply a parallel model reference adaptive fuzzy controller to control the object.

The content of the article with simulation results on real objects is the heating equipment in the laboratory of the Experimental Central of Thai Nguyen University of Technology (tnut.edu.vn) showing the superiority of applying the parallel model reference adaptive fuzzy control and can be implemented to control the high-capacity resistors that are actually being used.

II. STRUCTURE OF THE PARALLEL MODEL REFERENCE ADAPTIVE FUZZY CONTROLLER

A. *Structure of parallel model reference adaptive control*

Structure of parallel model reference adaptive control as shown in (Figure 1)

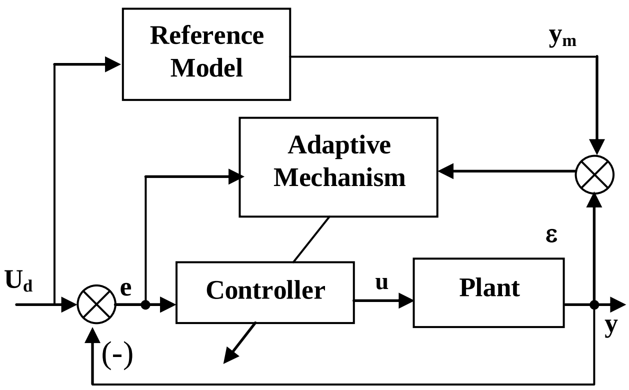

Figure 1. Structure of parallel model reference adaptive control

With the control object is described by the equation:

$$\frac{dy}{dt} = -ay + bu \quad (1)$$

The reference model is expressed by:

$$\frac{dy_m}{dt} = -a_m y_m + b_m u_d \quad (2)$$

The control signal:

$$u = K_1 u_d - K_2 y \quad (3)$$

With errors $\varepsilon = y - y_m$. This expression contains the adjustment parameter. The problem is finding the adaptive mechanism to adjust the parameters K_1 and K_2 so that $\varepsilon \to 0$. We can apply Lyapunov stability theory or Gradient method [4]

In this paper we only use adaptive law according to Lyapunov. Assume $b\eta > 0$ and choose Lyapunov function:

$$V(\varepsilon, K_1, K_2) =$$
$$= \frac{1}{2}\left[\varepsilon^2 + \frac{1}{b\gamma}\left(-bK_2 - a + a_m\right)^2 + \frac{1}{b\gamma}\left(-bK_1 + b_m\right)^2\right]$$

According to the regulating law, the parameters K_1 and K_2 for $\varepsilon \to 0$

$$\frac{dK_1}{dt} = \gamma u_d \varepsilon$$

$$\frac{dK_2}{dt} = -\gamma y \varepsilon$$

B. Structure of the parallel model reference adaptive fuzzy controller

In order to get the parallel model reference adaptive fuzzy controller, from figure 1 we simply replace the classic controller with the basic fuzzy controller with 2 inputs: error (e) and derivative of error (de / dt) with the output amplifier coefficient K can be changed. This fuzzy controller can be expressed as F.e plus a delay T as expression (4) (figure 2). The delay limit T will approach 0 when the system reaches the equilibrium point [6] .

$$u = K(T + F.e) \qquad (4)$$

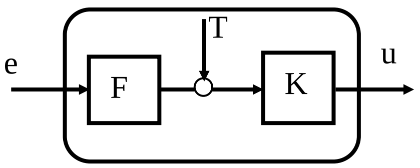

Figure 2. Fuzzy controller with output amplification factor K

where $F = \frac{B}{A}\gamma_I S = \frac{B}{A}\gamma_I K_I(\lambda + I);$

$$S = E + R = K_I(\lambda + I)e;$$

γ_I is nonlinear parameter

λ is input amplifier coefficient

We apply the Lyapunov method to adjust appropriately the output amplifier coefficient K of the fuzzy controller

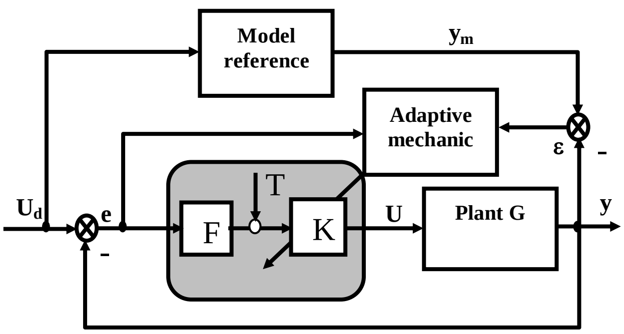

Figure 3. Adjustment structure of output amplification factor according to MRAFC

The closed loop system around equilibrium becomes linear with the equation of the closed loop:

$$y = \frac{KFG}{1 + KFG} u_d$$

Assuming y approaches y_m, then we can approximate

$$\frac{KFG}{1 + KFG} \approx G_m$$

$$\frac{\partial \varepsilon}{\partial K} = -\frac{\partial y}{\partial K} = -\frac{KFG}{1 + KFG} \cdot \frac{e}{K} \approx -G_m \frac{e}{K} \qquad (5)$$

Then the law of adaptive adjustment for output amplification coefficient of FLC according to Lyapunov can be determined from (4):

$$K = \gamma \frac{1}{s} u_c \varepsilon \qquad (6)$$

With the coefficient γ in (6) indicates the convergence rate of adaptive algorithm.

Similar to the adjustment of one parameter, we add the second parameter K_I to the adaptive adjustment algorithm as shown (Figure 4).

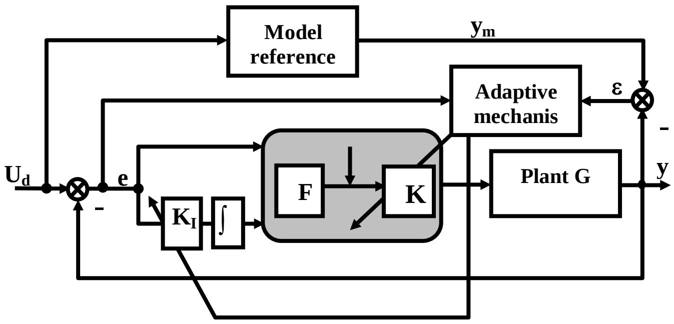

Figure 4. Adjustment structure of output amplification factor and input bias deviation factor according to MRAFC

Then the law of adaptive adjustment is determined according to Lyapunov

$$K = \gamma \frac{1}{s} u_c \varepsilon$$

$$K_I = -\gamma \frac{1}{s} u e$$

Based on the above establishment, we will apply the control structure to the real object that is the heating device in the laboratory of the Experimental Center of Thai Nguyen University of Technology to control and simulate.

III. INTRODUCTION OF THE CONTROL SYSTEM IN THE LABORATORY

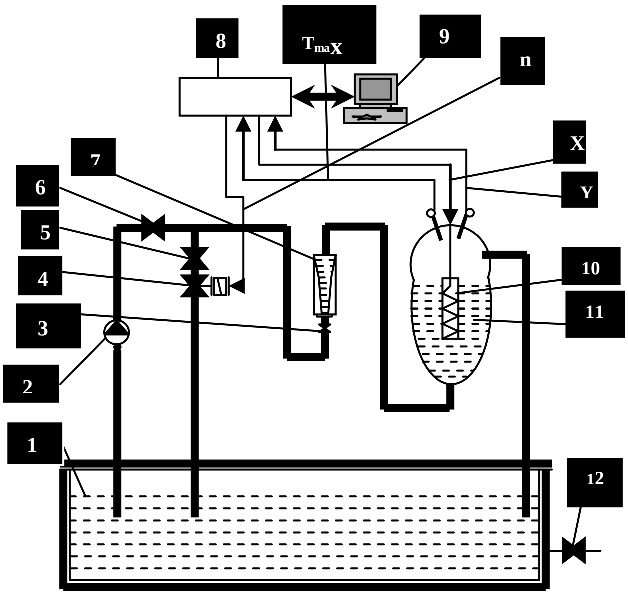

Figure 5. The control system in the laboratory

Where:

1. Water container
1. Centrifugal pump.
2. Flow control valve
3. Automatic magnetic valve for noise interference.
4. Noise flow control valve.
5. Control valve
7. Flow meter
8. Control block
9. Computer
10. Thermal resistance.
11. Water bottle contains 2 temperature sensors.
12. Drain valve

X: Executive signal
Y: Control signal
n: Noise signal
Tmax: Safety control signal.

Control unit 8: Single-phase AC converter provid voltage for the thermistor, the adjustment of tl opening angle of Thyristors is achieved by tl TCA780 IC and the controller, measurement device signal amplification.

Control object: According to the structure diagram the system, we see that the water contained in the tank (12) is heated by a thermal resistor (10), its power supply is taken from the block (8).

The problem in this paper is that with the available parameters of the system in the laboratory, we use an adaptive fuzzy controller instead of existing classic controller for control and simulation to improve system quality.

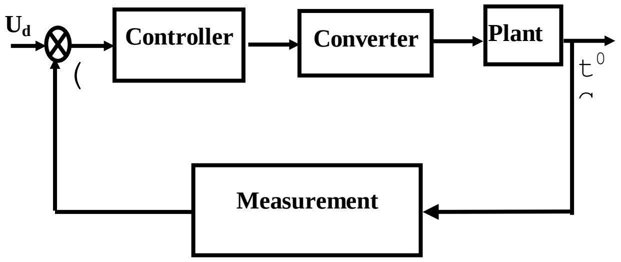

Figure 6. Control structure diagram

Identifying the thermistor control object is the first order transfer function:

$$W_{DT} = \frac{\alpha e^{-\tau p}}{\beta p+1}$$

Transfer function of AC-AC converter - single phase

$$W_{BBD} = \frac{22}{1+0,00333p}$$

Transfer function of feedback stage: including measurement and amplifier with transfer function as follows:

$$k_{fh} = W_{DL} * W_{KD}$$
$$=0,051*9,069 = 0,4545$$

The reference model used is the first order function

$$W_{MH} = \frac{1}{0.5s+1}$$

IV. SIMULATION WITH MATLAB SIMULINK

To clearly see the advantages of the proposed algorithm, compare the control results between the classic PID controller and the adaptive fuzzy controller according to the model model in some cases as follows:

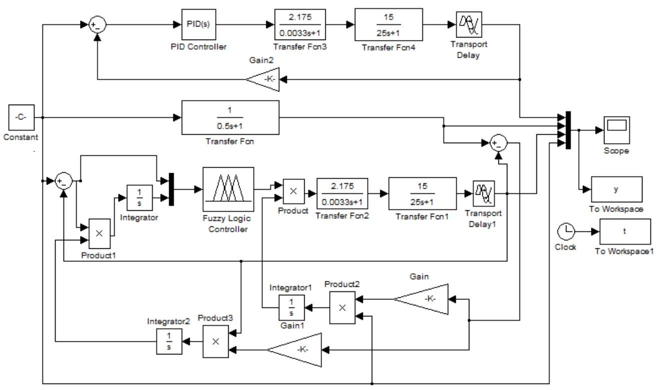

Figure 7. Structure of simulation employing Matlab Simulink

Simulation results

+ Case 1: The object of a thermal furnace has parameters:

$$\alpha = 4; \beta = 20; \tau = 0$$

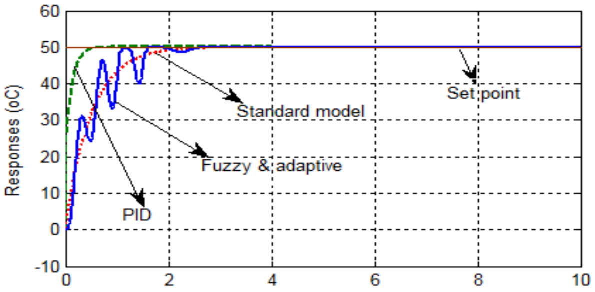

Figure 8. Comparison of control signal of PID controller and MRAFC ($\alpha = 4; \beta = 20; \tau = 0$)

+ Case 2: The object of a thermal furnace has parameters:

$$\alpha = 20; \beta = 20; \tau = 0$$

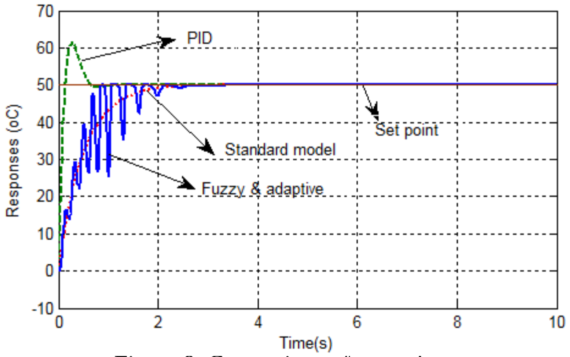

Figure 9. Comparison of control performance of PID controller and MRAFC ($\alpha = 20; \beta = 20; \tau = 0$)

+ Case 3: The object of a thermal furnace has parameters:

$$\alpha = 15; \beta = 25; \tau = 0.2$$

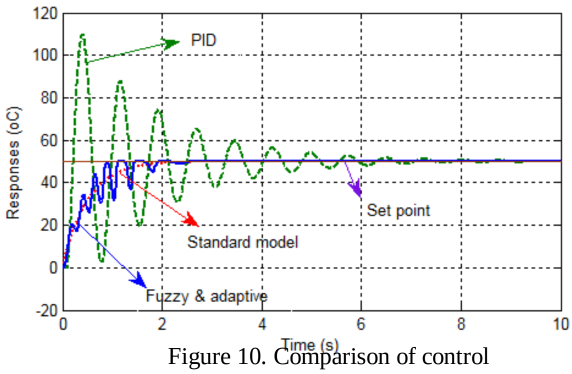

Figure 10. Comparison of control performance of PID controller and MRAFC ($\alpha = 15; \beta = 25; \tau = 0.2$)

V. REMARKS

With the simulation results in Figure 8 shows that when the coefficient of amplification, time constant of fixed objects (and not considered delay) with the simulated parameters such as case 1, the quality of PID control is better than the adaptive fuzzy controller, because the calculation time of the fuzzy controller is longer and must follow the model reference. However, both controllers ensure the quality of the control system. In Figure 9, when changing α, maintaining the value of the remaining parameters such as case 2. Figure 10 shows the results when changing all 3 parameters of the object such as case 3 we find that the dynamic characteristics of the fuzzy control system adapt much better than the PID controller, the PID controller has shown poor control quality, there has been over-shoot as well as signs of instability when $\tau \neq 0$. The MRAFC has a relatively simple structure, easy to implement, able to respond well when the object is delayed and has changeable parameter. Therefore, it is possible to use a model reference fuzzy adaptive controller to control thermal objects in practice.

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