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Research on the Design of Ceramic Kiln Control System Based on PID

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In this paper, the author discussed the application and design of ceramic kiln control system based on PID. Ceramic kiln plays a very important role in the process, and the level of automation in kiln determines the development of the ceramic industry. The firing of ceramic kiln is a thermo technical process with the variation of time, large time delay and much interference. The temperature control system is the core of the whole ceramic kiln control system. In this paper, in order to improve a wide range of temperature control accuracy, by combining fuzzy and PID control methods a fuzzy PID temperature control system of the thermal analyzer based on ARM microprocessor is designed and implemented. In this paper, the hardware has been designed by using 32-bit ARM7 processor LPC2368 as the core. The system selected the temperature sensor of Platinum-Rhodium thermocouple. The zero-crossing detection opt coupler devices and TRIAC make up the implementation unit. Human-computer interaction interface composes of the key and LCD.

1. Introduction

Ceramic kiln plays a very important role in the process, and the level of automation in kiln determines the development of the ceramic industry. The firing of ceramic kiln is a thermo technical process with the variation of time, large time delay and much interference (Jing et al., 2008).
It’s a broad application to measure and control temperature in the industry production. Especially in some industry, such as oil, chemistry, electric power, metallurgy. The temperature control directly impacts on the quality of the product and industrial production process (Dinh and Afzulpurkar, 2007; Yang et al., 2012). With the rapid development of the microelectronics technology, the embedded technology and the automatic control theory, the temperature control technology is in the trend of intelligence development. In this paper, on the basis of relevant research both at home and abroad, process control for industrial temperature control system, and aiming at the feature of bad expand D/A ability, the bad disposal of complex controlled environment and the nonsupport of fulfilling the real-time multi-tasking, an industrial fuzzy PID temperature control system based on ARM is proposed. In hardware, the system adopt ARM9 embedded micro controller as the main control chip, the temperature detection module and LCD module have been designed, and the storage unit has been extended. In addition, in order to download D/Ata, system debugging and with the PC machine or device to communicate more easily, the system also design to RS232 serial port circuit, JTAG circuit and Ethernet interface circuit; In software, the kernel of embedded real-time operating system Linux was cut, configured, compiled and transplant in the final. In addition, the programming of applications of temperature detection module, D/A D/Ata acquisition module, LCD module and the control algorithm module has been design. The temperature control system with this method, overcome the shortage of traditional PLC and SCM control, the system has many advantages such as good expand D/A ability, high reliability, fast response, small size and more intelligent, etc. In this paper, the algorithm of temperature control in industrial production process has been studied, finally, fuzzy PID control was chosen as the control algorithm in this temperature control system. To the boiler steam temperature as control object, a simulation model with the temperature control system of industrial boiler steam has been established. The result show that the fuzzy PID control effectively improve the system capacity, such as nonlinear, time variability and uncertainty, get better control effect.

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2. Overview

The mathematical model of the controlled process could be established through analysing its mechanism according to the relation of material balance and energy balance with mathematical description, this method has much universality. The car spray-paint workshop is divided into 2 floors, also its length is 260m and width is 50m, building area is about 26000m². The first floor are placed the office and machine equipment's, on the second floor is the ceramic kiln system which is made up of 5 big assembled ceramic kiln equipment's. The big assembled ceramic kiln equipment's can produce the work demanded air and send it to all over the workshop. In normal situation, 5 assembled needs to send 280000 m3/h air (Jin et al., 2008; Zhu and Wan, 2011; Chen et al., 2009).

From the Fig. (1), we can see that when the ceramic kiln is working, the two fans are running, outside fresh air enters the ceramic kiln system through the "air in gate", then into the first filtration system which can make air clean, then into the heat machine which can heat the air at a certain value, after that the air is filtrated again, then it enters spouting water system which can make air wet to reach a certain humidity, finally the air enters the workshop by "air out gate".

3. Modeling of ceramic kiln control system

In order to demonstrate the effectiveness of the proposed microcontroller based PID controller a dc-dc converter system was chosen for the practical implementation. The phenomenal advancement in technology has given rise to modern electronic systems that require reliable, high quality, efficient, small and lightweight power supply system. This has inspired the wide use of dc-dc systems in many industrial and electrical systems. The main function of a DC-DC converter is to convert a fluctuating DC input voltage into a regulated DC output voltage and supply it to a variable-load resistance. DC-DC converters are mostly applied in applications such as computers, television receivers, communication devices, medical instrumentation, battery chargers and many other devices that require regulated DC power. DC-DC converters are also used for DC motor speed control applications to provide regulated variable DC voltage. The dcdc converters can be found as step down (buck) or step up (boost) converters. In this project the buck converter system was chosen for our analysis and demonstration of the microcontroller based PID controller. In order for a buck converter to maintain a constant voltage output, it employs a feedback or closed loop system which continuously monitors the output voltage and takes corrective action whenever the output voltage shifts away from the desired value. What this corrective action does is to change the duty cycle of the signal driving the MOSFET. Our proposed micro-controller based PID controller was going to be that feedback loop which adjusts the duty cycle of the MOSFET to maintain a constant output voltage on our converter (Mezquita et al., 2014; Sonnemann and Chhay, 2014).

Because there are many uncertain factors within the room, it's impossible to correctly determine the mathematical model of the ceramic kiln room temperature through process identification. The mathematical model of the controlled process could be established through analysing its mechanism according to the relation of material balance and energy balance with mathematical description, this method has much universality. Because the space of the controlled ceramic kiln room is typically large, the change of temperature and humidity is unreactive, there is strong anti-interference capability by itself, and therefore we decided to establish the mathematical model of the controlled process through mathematical derivation. At the same time, we know that the temperature and humidity of the room are determined by many factors, such as the temperature and humidity of the outdoor atmosphere, the structure and material of the external wall, the orientation of the room, the power of the heating equipment within the room, the quantity of people and the working nature of the people, and these factors have their own uncertainties, so it's difficult to get the accurate mathematical model of the ceramic kiln room temperature (Krmpotic, 2015).

The flow characteristic of the regulating valve is the relation between the relative flow of the regulating valve and the relative opening of the regulating valve, and its function expression is (Schnepp et al., 2016; Zhu and Li, 2014):

$$\frac{Q}{Q_{\max}} = f(\frac{l}{L}) \tag{1}$$

Relative flow Q/Q_{max} is the ratio of the flow under certain opening Q to the flow under full opening Q_{max} of the control valve. Relative opening l/L is the ratio of the travel under certain opening l to the travel under full opening L of the control valve. The electric regulating valve selected in this project has equal percentage (logarithm) flow characteristic, the function expression of the regulating valve is:

$$\frac{Q}{Q_{\max}} = R^{(\frac{l}{L}-1)} \tag{2}$$

According to the model of the electric valve we selected, R=30. In this project, the opening of the electric valve is controlled by the voltage of 0-10V, the control voltage is expressed as ΔU, so expression (2) is changed to:

$$Q(t) = \frac{Q_{\max} * 30^{\frac{\Delta U}{10}}}{30} \tag{3}$$

DN25 electric regulating valve is used in this unit, the heating capacity of the valve under full opening is 150KW, and the vapour volume flowing through the valve is 0.15m^3/s, which is substituted into the above expression (3), the result is

$$Q(t) = 0.004 * 30^{\frac{\Delta U}{10}} \tag{4}$$

In this ceramic kiln system, 0.2Mpa vapour is used as the heat source of the heating air of the heating coil. Just like the ordinary heat exchanger, it's considered that the heat dissipated from the heater is approximately equal to the heat absorbed by air flowing through the heater, thus we establish the following equation:

$$1.2 C_P Q_K \Delta t = rCQ_S \tag{5}$$

Where, Cp is specific heat at constant pressure of air; Cp=1.01KJ/kg*°C; Qk is the air volume flowing through the heater m^3/s; in this design, the combined ceramic kiln system is constant air volume air supply system, Qk=6.5m^3/s; r is the latent heat of vaporization of 0.2Mpa vapour, r=2164 kg; C is the specific gravity of 0.2Mpa vapour, C=1.651kg/m^3; Δt is the temperature rise of the air after flowing through the heater, in °C; Qs is the vapour flow entered into the heater, in m^3/s
Substitute the above known quantities into the above expression (5), the result is:
Δt=450Qs, the result after Laplace transform is :

$$\frac{\Delta t(s)}{Q_S(s)} = 450 \tag{6}$$

The volume of the plant ceramic kiln area is V (m^3), the indoor temperature is tn (°C), the outdoor temperature is tw (°C), the air supply temperature is ti (°C), the heat supplied into the room by the unit is Qi (kJ/h), the air exchange rate of the ceramic kiln room is n(1/h); the heat generated by the machines and persons within the plant is Qm (kJ/h); the specific heat at constant volume is Cv (kJ/ m3*k), the parameter regulated is the indoor air temperature tn (°C).
The heat dissipated from the ceramic kiln room is Q_{out}, the heat taken by the return air is $Q_{out,a}$, and the heat permeated through the enclosure is $Q_{out,b}$, i.e.:

$$Q_{out} = Q_{out,a} + Q_{out,b} = nC_v V t_n + Q_{out,b} \tag{7}$$

The heat input into the ceramic kiln room Q_{in} is the heat input through air supply $Q_{in,n}$ and the heat generated by the machines and persons within the room Q_p,

$$Q_{in} = Q_{in,n} + Q_p = nC_v V t_i + Q_p \tag{8}$$

The heat storage capacity of the indoor air W is:

$$W = C_v V t_n \tag{9}$$

Assuming that the enclosure and equipment don't store heat, then the equation of heat storage capacity change of the ceramic kiln room is

$$\frac{dW}{dt} = Q_{in} - Q_{out} \tag{10}$$

Substitute (7), (8), (9) into (10), the result is

$$C_v V \frac{dt_n}{dt} = nC_v V t_i + Q_p - nC_v V t_n - Q_{out,b} \tag{11}$$

For simplifying calculation, assuming the enclosure doesn't transfer heat, ignoring the heat generated by persons and equipment, then $Q_{out,b}$=0, Q_p=0 substitute it into (11), then the result is

$$\frac{dt_n}{dt} = nt_i - nt_n \tag{12}$$

After Laplace transform, the equation (12) is:

$$\frac{t_n(s)}{t_i(s)} = \frac{1}{\frac{s}{n}+1} \tag{13}$$

In the plant, the volume of the area controlled by one ceramic kiln is 2800m^3, the air supply volume of the combined ceramic kiln is 50000m^3/h and the air exchange rate per second of the room is: n=50000/(2800∗3600)=0.00496, substitute it to (13), the result is:

$$t_n(s) = \frac{1}{202s+1} t_i(s) \tag{14}$$

The distance between the ceramic kiln area and the unit is 50m, which are connected via air duct, the air speed of the air supplied by the ceramic kiln is 7m/s, then there is about 7s delay of the room's ceramic kiln, therefore the transfer function of the area to be conditioned is

$$t_n(s) = \frac{1}{202s+1} e^{-7s} t_i(s) \tag{15}$$

Substitute (4) into (6), then the temperature rise of the unit is: $\Delta t = 1.8 * 30^{\frac{\Delta U}{10}}$, derive

$$t_i - t_w = 1.8 * 30^{\frac{\Delta U}{10}} \tag{16}$$

For simplifying calculation, assuming the outdoor temperature varies linearly with time tw=13sin((t-6)π/12)-7, the original point of t is 0.

4. Algorithm simulation of ceramic kiln system temperature control

According to the transfer function (15), we established the simulation model as Figure 1. with Simulink of Matlab, if disturbance signal is considered, the system will become unstable, traditional PID control cannot meet the requirements. In order to stabilize the system, we designed a fuzzy PID adaptive control.

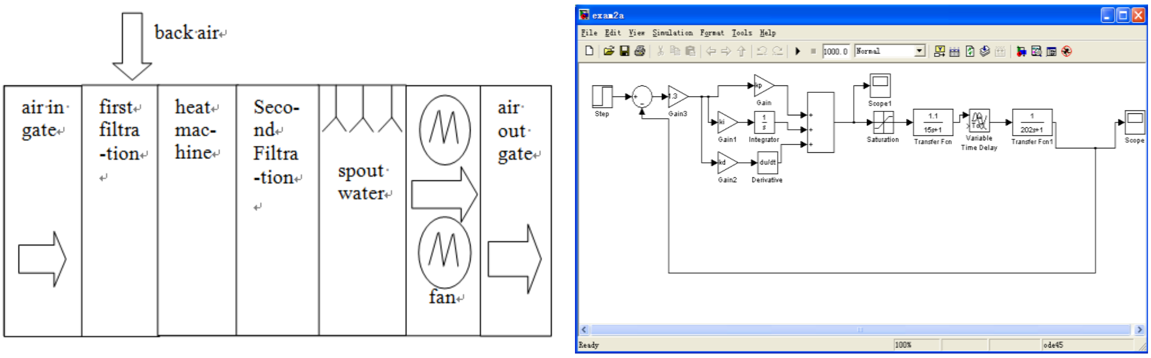


Figure 1: (a) Structure diagram of the assembled ceramic kiln and (b) Simulation model

First, we should choose the fuzzy variables of Kp, Ki, Kd, which are listed in table 1. Then, we choose fuzzy variables of E and EC, which are listed in table 2.
An intelligent adaptive control algorithm is designed in Matlab to see Figure 2.

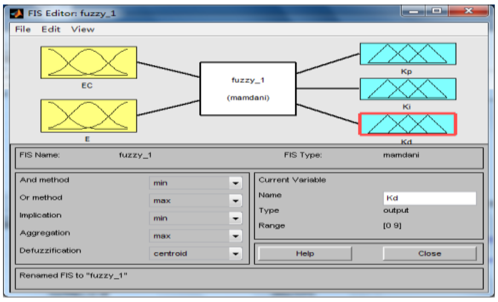
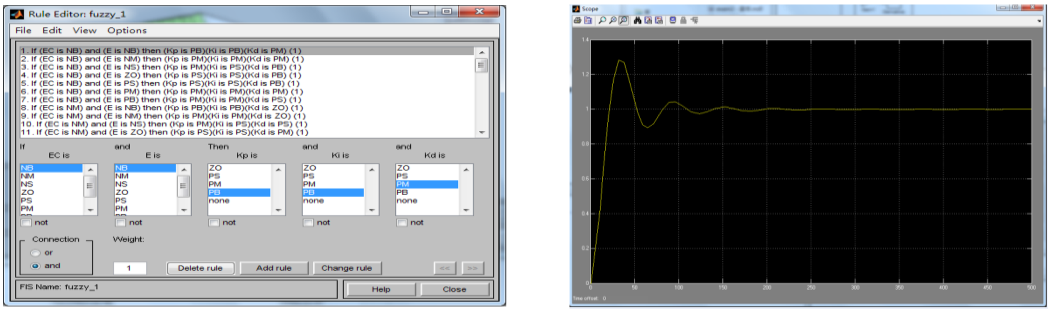


Figure 2: PID adaptive control simulation algorithm

According to the actual running state of the ceramic kiln, we use MATLAB to establish the fuzzy rules in Figure 3(a). when the ceramic kiln is working, the two fans are running, outside fresh air enters the ceramic kiln system through the “air in gate”, then into the first filtration system which can make air clean, then into the heat machine which can heat the air at a certain value, after that the air is filtrated again, then it enters spouting water system which can make air wet to reach a certain humidity, finally the air enters the workshop by “air out gate”.



(a) (b)

Figure 3: (a) PID rules and (b) PID adaptive control simulation char

The PID adaptive control simulation result chart is in Figure 3 (b).

Table 1: Fuzzy variables of Kp, Ki, Kd

Var	0	1	2	3	4	5	6	7	8	9
Z0	1	0.67	0.33	0	0	0	0	0	0	0
PS	0	0.33	0.67	1	0.67	0.33	0	0	0	0
PM	0	0	0	0	0.33	0.67	1	0.67	0.33	0
PB	0	0	0	0	0	0	0	0.33	0.67	1

Table 2: Fuzzy variables of E and EC

Var	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6
NB	1	0.5	0	0	0	0	0	0	0	0	0	0	0
NS	0	0	0	0.5	1	0.5	0	0	0	0	0	0	0
Z0	0	0	0	0	0	0.5	1	0.5	0	0	0	0	0
PS	0	0	0	0	0	0	0	0.5	1	0.5	0	0	0
PB	0	0	0	0	0	0	0	0	0	0	0	0.5	1

Control engineering is one of the most important part of modern day industries. Its main objective is to avoid disturbances and ensure the desired output in industrial processes. One of the generic control strategies that is widely used in industrial control is the Proportional Integral and Derivative (PID) control algorithm. The PID controller has been deemed by some experts to represent the ultimate in control of continuous processes for which a specific mathematical description (transfer function) can be written. The PID controller in all its ability to eliminate steady-state errors and anticipate the future through integral action and derivative action is a simple implementation of the feedback principle. More than 95 percent of the control loops in process control are of PID type; a greater number of those loops are actually PI control. PID controllers come in many different forms. They can be implemented as stand-alone systems in boxes for one or a few loops or as distributed systems for process control. Even systems which are as diverse as atomic force microscopes, cars cruise control systems, or CD and DVD players contain PID controllers. Because they are sufficient for many control problems with benign process dynamics and modest performance requirements, they are found in large quantities in almost all industries.

For many years the PID controllers have been implemented in analog format. After their introduction, these electronic controllers gradually excelled in performance over their mechanical predecessors, both in terms of performance, speed and cost. As result single loop analog controllers have enjoyed a steady popularity and they have reached the highest level of sophistication due to the rapid advances made in the industry. But the use of these analog PID controllers however always presented difficulties in changing the controller parameters whenever there are changes in plant dynamics due to changes in the operating conditions. This scenario always required the engineer to change the hardware in order to change the controller parameters to match with the new operating conditions. During that time digital computing had not yet advanced and it was very slow and costly compared to the situation today. There was little software available and machine code was used to program the required solution to engineering problems.

5. Conclusions

In China, when people do actual engineering projects of factory ceramic kiln, due to the influence of input temperature change and other disturbance, regular PID control method cannot meet the demand of temperature control system. So, in order to solve the temperature control problem, this paper explored the model of the temperature control system and established the model of the ceramic kiln.

Also, we designed the fuzzy PID adaptive algorithm and carried out simulation on the model in Matlab, through the simulation result in Fig. (5), it could be seen that the control temperature value could reach the set temperature value stably.

We have applied the algorithm to the actual control system, the actual temperature control system of the ceramic kiln has been running for more than 3 years and it is in a good condition. Practice shows that the fuzzy adaptive PID controller has been completely met the system’s control demands. Obviously, the ceramic kiln model established in this paper is very important and useful to study the temperature control of the ceramic kiln.

Reference

Chen J., Cheng M., Xu G., Huang B., Li J., 2009, Research on characteristic and intelligent logic control for temperature process in ceramic roller kiln, Journal of Wuhan University of Technology, 31(2), 100-103.

Dinh N.Q., Afzulpurkar N.V., 2007, Neuro-fuzzy MIMO nonlinear control for ceramic roller kiln, Simulation Modelling Practice and Theory, 15(10), 1239-1258, DOI: 10.1016/j.simpat.2007.08.005.

Guadarrama J.J., Chavez R.H., 2017, Automatic control of coupled brick kilns, Chemical Engineering Transactions, 56, 1933-1938, DOI: 10.3303/CET1756323.

Jing C., Chun X., Kui X., 2008, Logic Control Algorithm Based on Panboolean Algebra and Its Application for Temperature Control of Ceramic Roller Kiln, The Workshop on Computational Intelligence & Industrial Application IEEE, 416-420.

Krmpotic D., 2015, Information impactogram application for fast detection of temperature instability zone of a two-channel ceramic roller kiln, Tehnicki Vjesnik, 22(4), 981-987, DOI: 10.17559/TV-20141202210129.

Mezquita A., Boix J., Monfort E., Mallol G., 2014, Energy saving in ceramic tile kilns: Cooling gas heat recovery. Applied Thermal Engineering, 65(1-2), 102-110, DOI: 10.1016/j.applthermaleng.2014.01.002.

Schnepp E., Leonhardt R., Korte M., Klett-Drechsel J., 2016, Validity of archaeomagnetic field recording: an experimental pottery kiln at Coppengrave, Germany, Geophysical Journal International, 205(1), 622-635, DOI: 10.1093/gji/ggw043.

Sonnemann T.F., Chhay R., 2014, Non-destructive GPR analysis of threatened Angkorian ceramic kilns at Bangkong, Siem Reap, Cambodia. Journal of Indo-Pacific Archaeology, 34, 42-50.

Yang S.Q., Liu B.L., Pei C.X., 2012, Distributed Control System of Ceramic Material Kiln Based on MVC, Advanced Materials Research, 490-495, 3182-3186.

Zhu Y., Wan J., 2011, Intelligent Temperature Control of Ceramic Kiln Based on Data Fusion Technology, Applied Mechanics & Materials, 128-129, 177-180.

Zhu Y., Li P., 2014, Research on Burning Zone Detection Method Based on Flame Image Recognition for Ceramic Roller Kiln, Applied Mechanics & Materials, 602-605, 1761-1767, DOI: 10.4028/www.scientific.net/AMM.602-605.1761.