The Design for the Boiler Drum Level System Based on Immune Control

GuiLi Yuan
School of Control and Computer Engineering, NCEPU, Beijing, China
Email: ygl@ncepu.edu.cn

JiZhen Liu
School of Control and Computer Engineering, NCEPU, Beijing, China
Email: xyg@ncepu.edu.cn

***Abstract*—Aiming at multi-disturbance characteristic of drum water level system, control system uses three impulse cascade control strategy. This paper designs three impulse cascade control combined of incomplete differential PID and immune P control, fully using the advantages of artificial immune feedback control and incomplete differential PID. Boiler drum level simulation result shows the cascade control based on immune feedback mechanism, can improve the system dynamic performance. The simulation results also prove the validity of the control strategy.**

***Index Terms*—immune principl,; incomplete differential PID, Immune Control, drum water level**

I. PREFACE

The automatic control task for feed water of boiler is to adapt the amount of feed water to the amount of evaporation, to maintain the water level in the specified range. Drum Level is an important control parameter or indicator for the boiler safe and stable operation and also an important part of automatic control. High water level will affect the separation for steam and water in drum, to increase the moisture content of steam, to deteriorate the quality of steam, and even to damage the blade of turbine. Low water level leads to the small amount of water in the drum. When the load is large, fast vaporization rate of water, which changes the amount of water in the drum very quickly, will vaporize all the water in the drum, causing the boiler to be burned out or exploded. Therefore, the water level control is one of the most important conditions to ensure the safe operation of the drum. Theoretical research of boiler drum level control strategy has been carried out for many years [1.2], forming many control methods which include single impulse control, double impulse control, three impulse control, intelligent control and so on, and control performance has been greatly improved [3.4.5.6.7]. Aiming to fast stability and quick response of artificial immune control, this paper introduces three impulse cascade control combined incomplete differential PID with immune P control, which effectively improves the control performance of boiler drum level system.

II. IMMUNE SYSTEM FEEDBACK CONTROL

A. Immune Feedback Mechanism

Immunization is a characteristic physiological response of the organism. Biological immune system can produce antibodies against invading antigens. After antibody and antigen binding, a series of reactions will occur. Antigen was destroyed by phagocytes or special enzymes effect. Immunization includes humoral immunity and cellular immunity. Immune response is completed by the interaction between different sub-groups T cell. T_H cell and T_S cell are important immune regulating cells. T cell plays a key role in the immune response ,which mainly draw on feedback regulation mechanism of T cell. For simplicity, this paper mainly considerate response between B cells and T cells, that is, the response in antigens (A_g), antibody (A_b), B cells, secondary T cells (T_H) and inhibited T cells (T_S). The main feedback mechanism: antigen presenting cells- APC digest antigens, and then pass the antigen information to T_H cells. And APC release lymphocytes to activate B cells to produce antibodies, to activate immune response. APC can also slowly activate T_S cells. When the antibody increases, activated T_S cells can suppress T_H cells and B cells to inhibit the immune response, and implement the inhibition mechanism to ensure the stability of the immune system. The mutual cooperation between inhibition mechanism and the main feedback mechanism carry out by rapid response of immune feedback mechanism to antigens and stable the immune system [4,9,10]. Humoral immune response process is

Manuscript received Apr. 8, 2011.
project number: 2007AA04Z163

doi:10.4304/jcp.7.3.749-754

shown in Fig. 1. Regulation of T cells in immune response is shown in Table 1.

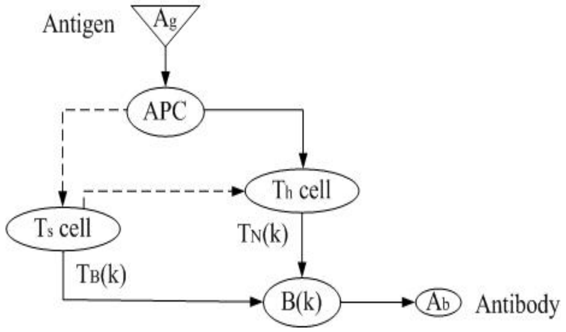

Figure 1. Humoral immune B cells response process

TABLE I. T CELLS' EFFECT IN IMMUNE RESPONSE PROCESS

Immune response process	Antigen concentration	Antibody concentration	Effect of T cells
Antigen invasion	large	min	---
The early of immune	large	small	Promotion
The late of immune	small	large	Suppression
The end of immune	min	large	---

According to Table 1, the effect of T cell at different immune response stages is different. In the early immune response, antigen concentration is large, but antibody concentration is small. Then T_H plays a major role to promote response process. In the late immune response, antigen concentration is small, but antibody concentration is large. Then T_S plays a major role to suppress response process to ensure stability of the immune system. When antigen concentration and antibody concentration are small, immune response is to an end, reaching stable immunity stage.

B. *Immune Feedback Control Algorithm*

Based on the immune feedback principle, assuming that antigen quantity in the k generation is $\varepsilon(k)$, T cell output is

$$T_H(k) = k_1 \varepsilon(k)) \tag{1}$$

Where:

k1: a stimulating factor of T_H cell, with a positive sign.

The influence T_S cell on B cell is $T_s(k)$.

$$T_s(k) = k_2 f(\Delta S(k))\varepsilon(k) \tag{2}$$

Where:

k1: Inhibitory factor of T_S cell, with a positive sign.

The total stimulus that B cell receives is $S(k)$.

$$S(k) = T_H(k) - T_S(k) \tag{3}$$

If taking the antigen quantity $\varepsilon(k)$ as a deviation, the total stimulus $S(k)$ the B cell receives as input $u(k)$. B cell's activity is given by integration to $S(k)$. Supposing the T cell amount is given by B cell activity differentiation, so T cell amount is $u(k)$. Feedback control law as follows:

$$u(k) = K\{1 - \eta f[\Delta u(k)]\}e(k) = k_p e(k) \tag{4}$$

Where:

$K = k_1, \eta = \dfrac{k_2}{k_1}$, $f(\cdot)$: The selected nonlinear function.

It plays the response role of T cell and external substances in $(k-d)$.K is used to control the reflect speed, η is applied to control stability effect [9,10,11].

Eq. (4) is immune feedback algorithm. The performance of immune feedback algorithm greatly depends on how to choose these factors including K,η , $f[\Delta u(k)]$. Seen from comparing Eq. (4) with the conventional digital PID controller, the controller based on immune feedback principle is actually a nonlinear controller [12].

Set $f(\Delta u)$ to $f(x)$, then

$$f(x) = 1 - \frac{2}{\exp(ax) + \exp(-ax)} \tag{5}$$

a :a parameter to change the functional form, $a > 0$. For different a, the input-output relationship of $f(x)$ is shown in Fig. 2. Seen from Fig. 2, the smaller a is, the more smooth $f(x)$ curves are. But to all x, $f(x) \in [0,1]$.

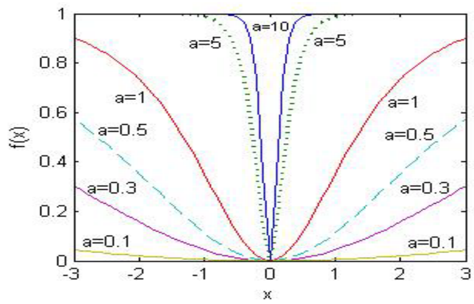

Figure 2. The relationship of $f(x) \sim \alpha$

III. THREE IMPULSE DRUM WATER LEVEL CONTROL SYSTEM

Boiler drum level is an important parameter to ensure safe production and high quality steam. And allowed fluctuation in water storage of drum becomes more and more small. Therefore, the water level must be strictly controlled within the specified scope. There are some problems in single impulse control and double impulses control, whose control effect is not satisfactory, so the usage of two control methods is given some restrictions. But the effect of three impulses control is excellent, so it is widely used. And the drum level control also applies three impulses control strategy. This paper uses three impulses control in design and simulation for control system of drum water level. Three impulses control system structure is shown in Fig. 3.

A. Principle of Three Impulses Drum Water Level Control System

Three impulses water level control system introduces the flow of steam as feedforward impulse to constitute drum level control system based on feedback control of flow. This system takes drum level, steam flow and water flow as the impulse to regulate the opening of water supply valve, to maintain the stability of water level. Three impulses water level control system takes drum water level as the main parameter, takes water flow as the feedback signal, and takes the steam flow as the feed-forward signal. By regulating feed water flow, we make the drum level change in the permitted range. The response characteristics that drum water level to changes of steam flow and water flow is positive. However, when load (steam flow) increases dramatically, the drum water level is to "counter response performance," that is, "false water level." The mechanism of this phenomenon: when the load increases, the drum pressure decreases, causing the boiling point of water in the drum drop. Then a sudden increase of water boiling produces a large number of bubbles, to make the water level elevate. Therefore how to overcome the "false water level" phenomenon is a key for drum water level regulation. At different stages, the dynamics characteristic of drum level continuously changes, the control effect of three impulses control which adopts a single structure and parameter is not satisfactory.

B. Mathematical Model of Three Impulses Drum Level Control System

Traditional three impulses drum level control method is shown in Fig. 3. a_D , a_W , a_H respectively represents the conversion coefficients of steam flow transmitter, water flow transmitter and differential pressure transmitter.

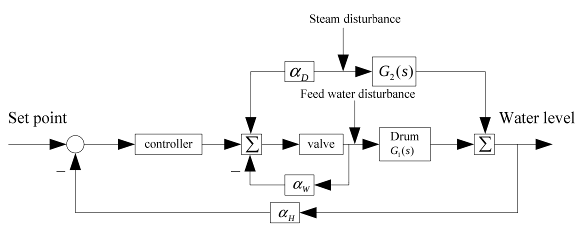

Figure 3. Drum level three impulses control system block diagram

This paper takes a boiler steam with supply capacity of 120t / h as example, and the experimental data can be measured as follows [12]:

The transfer function of feed water flow to water level is:

$$G_1(s) = \frac{H(s)}{w(s)} = \frac{0.0529}{s(8.5s+1)} \tag{6}$$

The transfer function of steam flow to water level is shown as follow:

$$G_2(s) = \frac{H(s)}{D(s)} = \frac{2.613}{(6.7s+1)^2} - \frac{0.0747}{s} \tag{7}$$

$$\alpha_D = 0.0667, \alpha_W = 0.0667, \alpha_H = 0.0667 \tag{8}$$

Valve gain is 15.

IV. IMMUNE PID-IMMUNE P CASCADE CONTROLLER DESIGN FOR BOILER DRUM LEVEL

A. Common Control Method: PI-P Cascade Three Impulse Control Method

The introduction of differential effect in the controller aims to improve the control quality of higher order object. Intuitively, differential effect conduct to control according to the change trend of the deviation, and the control is clearly a timely control. But when the instantaneous deviation is large, the output of differential item dramatically increases, easily leading to oscillate in control process, leading to decrease regulating quality. This is not allowed. Thus the PI-P cascade control is often used. The master controller:

$K_i = \frac{K_p}{T_i} = 0.045$,and deputy Controller: $K_p = 16$ [12].

B. Parts of the Scene, the Incomplete Differential PID-P Cascade Three Impulses Control Method in Some Job Sites

Seen from Eq. (9), the controller transfer function adds a zero after the introduction of incomplete differential. If the zero can cancel the object high pole, the controller transfer function become to a low-order process, if configured properly, it is clearly beneficial. With the improvement of power plant control requirements, some work site introduces the incomplete differential.

Taking incomplete differential PID control method transfer function as follows:

$$U(s)/E(s) = K_p(1+\frac{1}{T_i s}) * \frac{T_D s+1}{1+T_f s} \tag{9}$$

After low-pass filter added to the PID controller, incomplete differential can effectively overcome the ideal differential with better control characteristics. Although incomplete differential is more complex than ordinary PID controller, it is widely applied due to excellent control characteristics in recent years. Take filter coefficients of low-pass filter:

$$K_p = 6, K_i = \frac{K_p}{T_i} = 0.045, T_f = 2, \quad T_d = 10 \ ,$$

and deputy controller: $K_p = 16$ [12].

C. Immune Incomplete Differential PID -Immune P Cascade Three Impulses Controller Design

Combined immune feedback mechanism, this paper designs immune incomplete differential PID -immune P cascade three impulses controller to control the drum water level, that is, the main controller adopts immune incomplete differential PID to control, P control is used vice controller.

Cascade control is widely used in power plant. deputy loop acts as a "coarse" role, while main circuit is used to perform "fine tune". The effect of two regulators in cascade control system is different. Master regulator has own independent setting, and its output be taken as vice controller setting, and vice regulator output signal is sent to the control valve to control the production process.

Cascade control only adds a deputy circuit in structure, but the control effect obviously become excellent.

(1) Vice circuit can fast regulate, and can effectively overcome the secondary disturbances.
(2) When vice-circuit parameter changes, the vice loop conduct to control to reduce substantially influence to output value.
(3) Vice-loop adjusts inertia of vice-loop to improve the response speed of overall system.
(4) Vice-loop can decline the non-linear surrounded by vice-loop.

Vice-loop usually applies proportional control to quickly adjust the vice loop, but generally the vice loop controller is a constant, such as the former two control methods. This paper take the immune proportional control as vice loop controller, full using the rapid response and quick stability control of immune control. According to the deviation changes within the inner loop to adjust the parameters of the controller in vice loop, the main controller applies incomplete differential PID. In short, control performance of three impulses water supply system can be improved through the immune principle.

D. Immune Incomplete Differential PID Main Controller Structure and the Immune P Vice Controller Structure

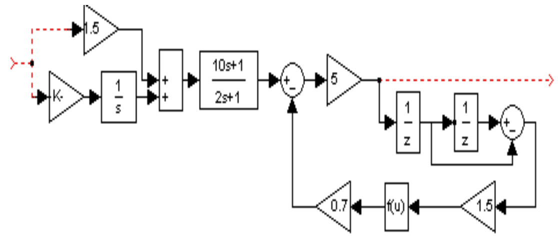

Figure 4 Immune incomplete differential PID main controller

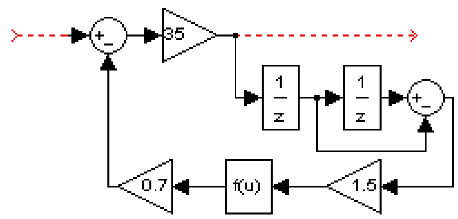

Figure 5 Immune P vice controller

After optimization, the main controller is:

$$(1.5+0.045\frac{1}{s})*\frac{10s+1}{2s+1}*5*(1-0.7f(1.5u)),$$

vice-loop immune controller is: $35*(1-0.7f(1.5u))$.

V. Simulation

Simulation uses SIMULINK toolbox in MATLAB.

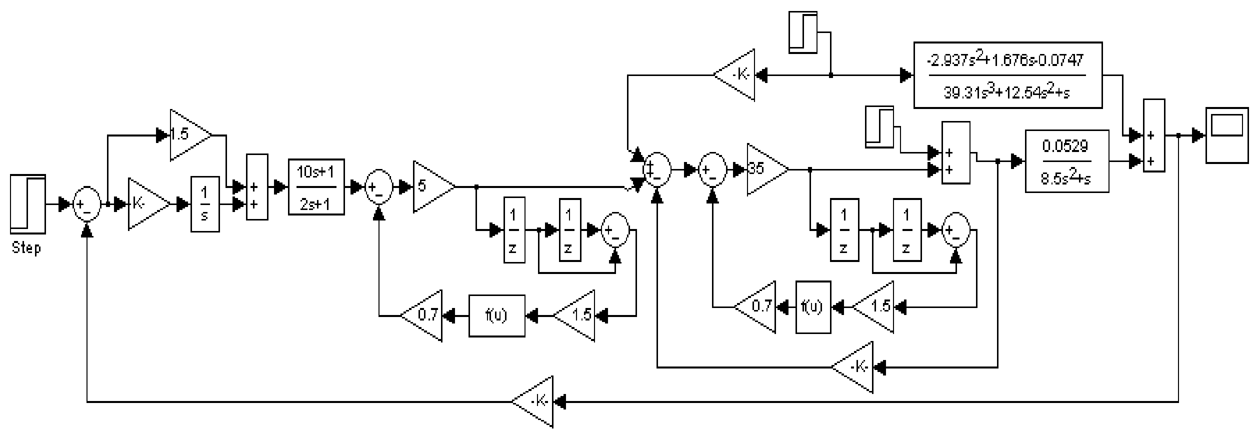

Figure 6 Immune incomplete differential PID -P cascade controller simulation diagram for feed water system

Immune incomplete differential PID -P cascade control simulation diagram is shown in Fig. 6.

When simulation is operated, the set value of water level is 1, corresponding to 30mm water column. When the system is stable (500 seconds), adding in 10% of the steam water disturbance or 10% feed water disturbance, that is 12t / h, the simulation curves are shown in Fig. 7~Fig. 12. These curves are responses corresponding to adding given input, adding feed water disturbance and adding steam disturbance, when the parameters is given, or K increases a double, or T increases a double.

Simulation results show that the control effect of curve 3 using immune incomplete differential PID-immune P cascade control is superior to the control effect of curve 2 adopting incomplete differential PID-P cascade control or the control effect of curve 1 using PI-P cascade control. Its settling time and overshoot is significantly reduced, and transition is smooth. At the same time, control effect using immune incomplete differential PID-immune P cascade control is better than that of five control strategies proposed in [12].

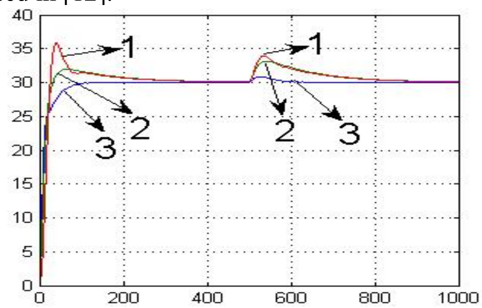

Figure 7. Nominal parameters, curves under feed water disturbance

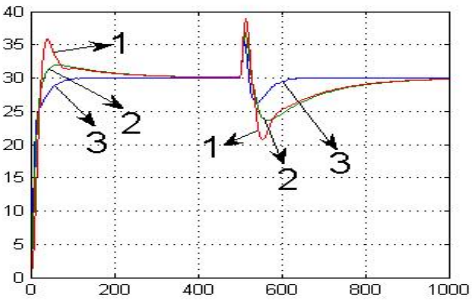

Figure 8. Nominal parameters, curves under steam disturbance

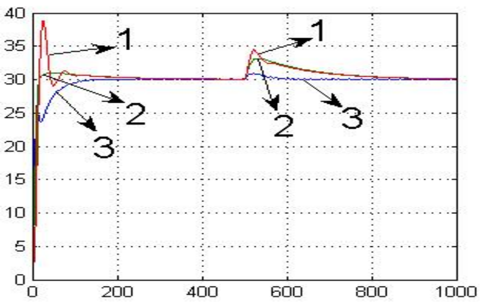

Figure 9. K increases a double, curves under feed water disturbance

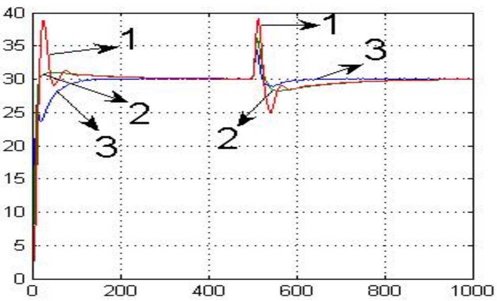

Figure 10. K increases a double, curves under steam disturbance

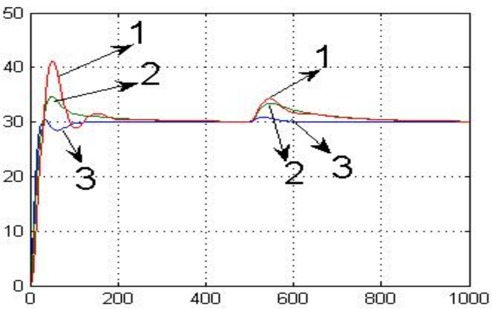

Figure 11. T increases a double, curves under feed water disturbance

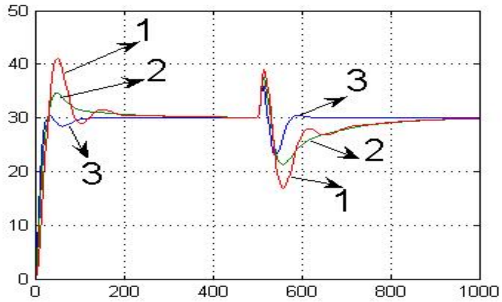

Figure 12. T increases a double, curves under steam disturbance

VI. CONCLUSION

This paper combines biological immune feedback mechanism based on incomplete differential PID -P cascade three impulses control, to propose immune incomplete differential PID -immune P cascade three impulses control method. Simulation results show, whether under given input or under disturbance, rated parameters or changed parameters, the control effect using immune incomplete differential PID-immune P cascade control is superior to these control effect adopting incomplete differential PID-P cascade three impulses control or PI-P cascade control. The response speed using this control method is very fast, and the system has a strong anti-interference ability. And its implementation is simple, so immune incomplete differential PID -immune P cascade three impulses control method has important practical value and significance.

ACKNOWLEDGMENT

This work was supported in part by Ministry of Science and Technology 863 Project (2007AA04Z163).

REFERENCES

[1] SUN, Xiu-quan, TANG, Jian, YU, Xiu-yin, *Boiler and industrial furnace pit for Computer Control Technology*, Beijing.National Defence Industry Press, pp.25-31, 1989.

[2] ZHANG, Xiao-hui, "Expert Control of the Steam-water Subsystem in Boiler", *Computer Automated Measurement & Control,* September 2001.

[3] XU, Chun-mei, ZHANG, Hao,YANG, Ping, "Nonlinear PID-P cascade control for boiler drum level.", *Journal of North China Electric Power University*, pp.44-47, 2003.

[4] WU,Jie.CHEN,Jiong.LI,Yi-guo, "Design of the immune control system for thermal engineering process and its stability analysis", *Control Theory & Applications,* pp.510-514, 2009

[5] WANG, Dong-feng, HAN, Pu, WANG, Guo-yu. "Predictive functional control for water level of boiler drum", *Journal of North China Electric Power University,* 2009

[6] LIU, Hong-jun, HAN, Pu, WANG, Dong-feng, "The DMC-PID of water level of boiler drum in Control and Simulation Research".pp.450-453,2004.

[7] PENG, Dao-gang, YANG, Ping, YANG, Yan-hua, "With Feedforward Compensation for Load Fluctuation of boiler feed water system of neural network internal model control", *China Academic Journal Electronic Publishing House,* 2005

[8] FU, Xiao-gang, "Application of the Fuzzy Immune PID

Control in Industrial Boiler Control System", *Boiler Technology*, pp.24-27, 2006.
[9] MO, Hong-wei, *The Principle and Application of Artificial Immune System*, Harbin Institute of Technology, November 2002.
[10] DING, Yong-sheng, REN, Li-hong, "A New Fuzzy Self-tuning Immune Feedback Control System". *CONTROL AND DECISION*, 2005.
[11] LIU, Jin-hun, *Advanced PID control and simulation with Matlab*, Beijng electric industry press, pp.189-190,2003.
[12] CHEN,Ping. "The research of fuzzy PID control in drum water level", HuaQiao University, 2006.

GuiLi Yuan NeiMengGu Province, China. Birthdate: October, 1971. is Control Science and Engineering Ph.D., graduated from School of Control and Computer Engineering North China Electric Power University. And research interests on information control, advanced control strategy and its application in power plant control.

She is a associate professor of School of Control and Computer Engineering North China Electric Power University.

JiZhen Liu Shanxi Province, China. Birthdate: Aug, 1951. is Control Science and Engineering M.E, graduated from School of Control and Computer Engineering North China Electric Power University. And research interests on optimal control of power plant.

He is a professor, and PhD supervisor of School of Control and Computer Engineering North China Electric Power University.