# PRINCIPLE OF FAST SELF-OPTIMIZING FUZZY CONTROL ON MICROCOMPUTER AND ITS APPLICATIONS[①]

Tian Chengfang[②] Li Jinhong[③] Wang Xueyin[④]
*North China University of Technology, Beijing 100041, China; Yanbian Teachers College*

**ABSTRACT**

This paper presents the control principle and working features of Fast self-optimizing Fuzzy Control (FSFC) system, including structure, technological features, objection of control, algorithm, determination of parameters and control scheme.

**Key word:** Fuzzy control, PID, FSFC.

The Fuzzy control has following common features; the controll object cannot be described with exact mathematical model, and its structure parameters are generally not clear or difficult to obtain. Furthermore, the control rules can be expressed qualitatively only in linguistic form. The theory of FSFC and its application described in this paper can be applied to adjust the parameters on-line. The control parameters of FSFC can be automatically adjusted and optimized on-line, the strategy of adjustment can be automatically chosen, and many kinds of interferences can be corrected rapidly. Thus, it can substitute any kind of regular feed forward correctors and make the industrial control process run in the best state. It has been proved that the performance of FSFC is better than that of the conventional controller[1-3].

## 1 THEORY OF FSFC IN SET-POINT CONTROL & ITS APPLICATIONS

The main parameters of the set-point adjustor are the response speed, peak overshoot, steady-state error, damping factor, adjusting time, etc.. The best state of controller is believed not only with the choice of the adjusting rules, but more importantly with the correction of the working parameters. For example, the correction of amplifiction $K_p$, integral factor $K_i$ and differential factor $K_d$ of PID controller have great effect on the quality of the controller. Taking $K_p$ for example, we know that its value is often stable or stable for the different periods in conventional scaling controller. This is the main cause for the steady state error. Especially in temperature-controlling processes, increasing $K_p$ will be helpful in reducing the steady state error and increasing the response speed. But excessive $K_p$ will make the system oscillate aggravatingly, leading to badly divergent oscillation. It has already been recognized that the value of $K_p$ should not be unchangeable in the

①Manuscript received Oct. 27, 1990
②Professor; ③Associate.professor; ④MSc

adjusting process. At the begining of the process, the $K_p$ should be larger in order to overcome the delay of some adjusting link and increase the response speed; in the middle of the process, the $K_p$ must be reduced according to the situation to prevent the excessive overshoot leading to fast oscillation; toward the end of the process, we must increase $K_p$ to overcome the steady state error. In conventional control systems, it is difficult to change the $K_p$ automatically on-line. But by using the FSFC technology, it is much easier[4,5].

For the same reason, we can use the FSFC technology to correct the working parameters in PI, PD and PID adjustors dynamically and automatically, thus attaining ideal indexes[2,6]. The diagram of FSFC system in set-point control is shown in Fig.1.

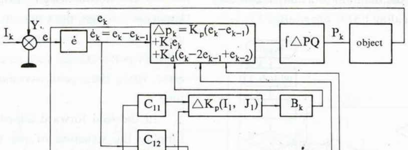

**Fig.1 The diargam of FSFC system**

Where: $\Delta K_p(I_1,J_1)$, $\Delta K_i(I_2,J_2)$, $\Delta K_d(I_3,J_3)$ ··· the modifications of $K_p$, integral factor $K_i$ and differential factor $K_d$ are determined by the FSFC according to the output error and its change.

$B_k$, $B_i$, $B_d$... scaling factors; $C_{11}$, $C_{12}$, $C_{13}$, $C_{22}$, $C_{23}$... quantifying factors;

$$K_p(k) = K_p(k-1) + B_k \Delta K_p(I_1, J_1);$$
$$K_i(k) = K_i(k-1) + B_i \Delta K_i(I_1, J_2);$$
$$K_d(k) = K_d(k-1) + B_d \Delta K_d(I_3, J_3);$$

Corresponding control rules can be made by summing up the operating experience in the process and describing it with groups of condition statements. In order to automatically modify the parameters of PID controller on-line, we use error $e$ and its variation $\dot{e}$ as the conditions making up the FSFC for the automatic correction of $K_p$, $K_i$ and $K_d$. Then three control tables are compiled and the Fuzzy relation R is calculated according to the effects of e and $\dot{e}$ on $K_p$, $K_i$ and $K_d$ respectively. On the basis of R, calculate each value of every grade of input $e$ and $\dot{e}$ to obtain the corresponding values of output respectively, make up the Fuzzy control table of $\Delta K_p(I_1, J_1)$,

$\Delta K_i(I_2, J_2)$, $\Delta K_d(I_3, J_3)$ (omitted). In the control process the real error $e$ and its variation $\dot{e}$ are transformed into the elements of Fuzzy set used quantifying factors $C_{11}, C_{12}, C_{13}, C_{21}, C_{22}, C_{23}$; The increment or decrement $\Delta K_p(I_1, J_1)$, $\Delta K_i(I_1, J_2)$, $\Delta K_d(I_3, J_3)$ from control table, are transformed into the actual modifications $\Delta K_p$, $\Delta K_i$, $\Delta K_d$ with the scaling factors $B_1, B_2, B_3$. Thus, the modifications $K_p$, $K_i$, $K_d$ may be adjusted automatically and rapidly.[6, 7]

Fig.2 is the diagram of a simple and easy Fuzzy logic scaling FSFC program.

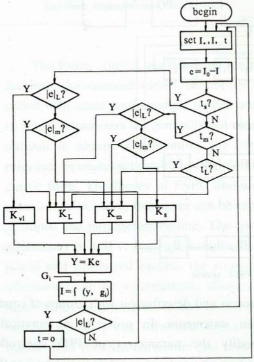


**Fig.2 The diagram of a fuzzzy logic scaling FSFC program**

* S–small, M–medium, L–large, VL–very large.

The algorithm is:

10 t←0 "begin"

20 t←t+1 " sampling instance"

30 if t is small, then {if $e$ is large, then $K$ is very large, else[if $e$ is medium, then $K$ is large, else $K$ is medium]}, else {if t is medium, then [if $e$ is large, then $K$ is large, else (if $e$ is medium, then $K$ is medium, else $K$ is small)], else[if t is large , then $K$ is medium , else $K$ is large]}

40 if $G_i$, then go to 10, else $K$ is large, "i = 1, 2, 3..., h".

50 if $I_0$, then go to 10, else $K$ is large. On running process, the parameter t is fuzzied to four grades (VL, L, M, S); the $e$ is fuzzied to three grades (L, M, S); and $k$ is fuzzied to four gades (VL, L, M, S).

In the above design, though the Fuzzy language is rough, the value of $K$ is automatically adjusted on line, which will improve the adjustor performance, such as the steady state error, rising time, peak overshoot and setting time.

In the feed forward adjustor, FSFC can simplify the structure of the system. In the conventional system, each interference should be equipped with a correct unit. In order to simplify the system, we can only choose some major interferences with the corresponding feed forward correct unit. With FSFC, the effect of many interferenes can be corrected simultaneously. The Fuzzy feed forward correction with the 40th multi-condition clause can do this work successfully. For this, we should append Fuzzy logic judgement clause as following:

if $G_1 = FL_{11}$, then{if $G_2 = FL_{21}$, then{if···, then(if $G_n = FL_{nb}$, then $Y = FL_b$, else $Y = FL_{b+1}$], else[if $G_2 = FL_{22}$, then··· ]}, else{if $G_1 = FL_{12}$, then [if $G_2 = FL_{21}$, then···], else[···]}

Where, $G_1, G_2 \cdots, G_n$ are the factors of interference, arranged from left to right in the order of their influence. $FL_{11}, FL_{12}, \cdots$ are the Fuzzy language values of $G_1$; $FL_{n1}, FL_{n2}, \cdots, FL_{n(b+1)}$, are the Fuzzy language values Fuzzy values of $Gn$'s. $F_1, F_2 \cdots Fl_{b+1}$ are Fuzzy language values of $Y$(decision)[3, 6].

## 2 THE THEORY OF FUZZY OF MODEL-REFERRED FSFC AND ITS APPLICATION

In some industrial control (such as the nonferrous metal-smelting and industrial furnace system), it is difficult to establish precise mathematical models, because the process itself is characterized by non-linearity, variation-with-time and large time lag. But if the model is established according to technolgical requirements and the experience of the manual operator, we can get satisfactory control by using model-referred FSFC.

Fig.3 is the diagrmam of the model-referred FSFC system. Here, A is the model consisting of technological requirements and manual control experience; B is the structure of FSFC, the inputs are error $e$ and its variation rate $\dot{e}$, the output varibles are the corrections $\Delta K_1$ and $\Delta K_2$ of the scaling coefficent $K_1$ and integral coefficient $K_2$ of PI respectively. The working principle is the same as that of Fig1.

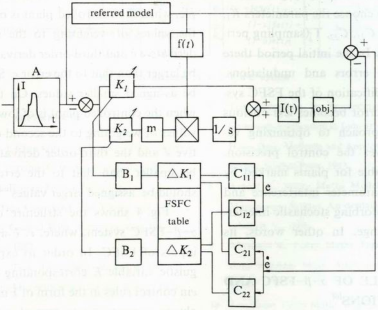


**Fig.3 The Diagram of Model-referred FSFC system**

There are two phases in the referred-model: a rising phase and a keeping phase. The setting point values are given by the time-array producer A. As the system is a model-followed process, the error is required to be within 0.1%. When calculating the Fuzzy table, we must carefully choose the quantifying coefficients $C_{11}$, $C_{12}$, $C_{21}$, $C_{22}$ and scaling factors $B_1$, $B_2$.

The leading effect of coefficents $K_1$ and $K_2$ varies during the control process. If the $\int K_2 edt$ is over integrated, it will influence the controlling effect of the scaling link and cause the change in the later process and the steady state error will be difficult to control. In order to solve this problem, we have introduced an uncoupling function to uncouple $K_1$ and $K_2$. Thus, in the beginning of the process, the effect of the $K_1$ is enhanced, and the effect of $K_2$ is reduced; in the later process, It is reverse.

This uncoupling function $f(t)$ must be an increasing one and changes as the process changes. The output value of referred model is a known increasing function which reflects the change of the process. Let the $f(t) = mI_s$ be used in the integration, where m is an uncoupling coefficient, and $I_s$ is the output value of the referred model. So we can write the regulator formula as follows:

$$I(nT) = I(nT-T)+K_1(nT)[e(nT)-e(nT-T)] + mI_s(nT)K_2(nT)e(nT)$$

$$K_1(nT) = K_1(nT-T)+B_1\Delta K_1(I_1,J_1)$$

$$K_2(nT) = K_2(nT-T)+B_2\Delta K_2(I_2,J_2)$$

At first, we can choose the parameters $K_1$, $K_2$, $B_1$, $B_2$, $C_{11}$, $C_{12}$, $C_{21}$, $C_{22}$, T (sampling period), and m roughly. In the initial period there may be significant errors and undulations. Along with the modification of the FSFC system of $K_1$ and $K_2$, error becomes less obvious and $K_1$ and $K_2$ approach to optimizing values, which improves the control precision. This system is suitable for plants marked by non-linearity and parameter interference and has the ability of absorbing stochastic interference and step change. In other words, its robustness is good[8,9].

## 3 THE PRINCIPLE OF $\alpha$–$\beta$–FSFC AND ITS APPLICATIONS[6]

Since the birth of Fuzzy controller, people have aimed at research on regulating Fuzzy control rules. In general situations, such as optimizing parameters of best control systems, adjusting the parameters of self-adapting control systems and identifying parameters of manual-operating Fuzzy control models, we always regulate the control rules. For this, we present the $\alpha$–$\beta$–Fuzzy control rules as follows:

Two dimensional $\alpha$–rule:

$$I(t) = [\alpha e(t)+(1-\alpha)\dot{e}(t) \quad (1)$$

Three dimensional $\alpha$–$\beta$–rule:

$$I(t) = [\alpha\beta e(t)+(1-\alpha)\beta\dot{e}(t)+(1-\beta)\ddot{e}(t)] \quad (2)$$

Where, $\alpha,\beta \in (0, 1)$. We can regulate the Fuzzy control rules by adjusting the coefficients $\alpha,\beta$. Using $\alpha,\beta$ to adjust parameters is not only convenient, but also has several profound physical meanings. Different values of $\alpha$ and $\beta$ express different degrees of weighting to the error $e$, second-order derivative $\dot{e}$ and third-order derivative $\ddot{e}$ respectively. This rightly reflects the thinking features of the operator when performing manual control. For example, when the controlled plant is of high-order, the values of weighting to the second-order derivative $\dot{e}$ and third-order derivative $\ddot{e}$ should be larger than that to the error $e$. So $\alpha,\beta$ should be as-signed smaller values. On the contrary, when the controlled plant is of lower-order, the values of weighting to the second-order derivative $\dot{e}$ and the third-order derivative $\ddot{e}$ should be smaller than that to the error $e$. So $\alpha,\beta$ should be assigned larger values[6,10].

Fig. 4 shows the structure of a genaral $\alpha$–$\beta$–FSFC system, where, $e$, $\dot{e}$ and $\ddot{e}$ are the inputs of FSFC. In order to express the linguistic variable $E$ corresponding to the error $e$in control rules in the form of Fuzzy set $E$, we always separate it into several grades; for the same reason, the linguistic varables $\dot{E}$, $\ddot{E}$ corresponding to the second-order derivative $\dot{e}$ and the third-order derivative $\ddot{e}$ must also be separated into several grades. We call this step discretization and fuzzification. After the modification of $\alpha$–FSFC algorithm, we get the Fuzzy set I of control linguistic variables. Then by using Fuzzy control decisions we get the exact control value I(t) to control the plant. Using a three-dimensional modifying factor control has many advantages, such as one-table for multi purpose, full use of the entire information, fast and optimizing operation, and overcoming the poor robustness of conven- tional Fuzzy control.

As $\alpha,\beta$ are the parameters which restrict and influence each other, according to the Fuzzy control rules, using the composing method with Fuzzy relation $R$ to compile the Fuzzy control table from which the values of $\alpha,\beta$ are determined by the changes of $e$, $\dot{e}$ and $\ddot{e}$, we can realize the adjustment of $\alpha,\beta$ on-line and achieve the best control of the Fuzzy industrial plant (black-box or grey-box system)[6,11].

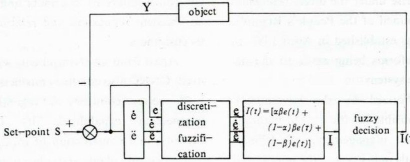


**Fig.4 The diagram of $\alpha$–$\beta$–FSFC system**

## REFERENCES

1 Zadeh L A (ed. ), Chen Guoquan(Trans. ). The Concept of a Linquistic Variable & Its Application to Approximate Reasoning. Beijing: Science Press, 1982

2 Wang Xuefei, Tian Chengfang. The Theory and Application of Fuzzy Control With Microcomputer. Beijing: Electronics Press, 1987

3 Wang Xuefei, Tian Chengfang. Industry Control Technigues With Microcomputer. Beijing: Atomic Energy Press. 1987

4 Tu Xiangchu, Wang Peizhuang. Fuzzy Maths. 1985(3): 81–85

5 Tu Xiangchu. J Beijing Polytech Uni. 1986, 12(2): 7–19

6 Tian Chengfang. In: Proceedings of the International Computer Application in Industry automation, 1990

7 Hong Deyi, Methods and Applications of Fuzzy Maths. Beijing: Science Press, 1983

8 Arnold K. Fuzzy Maths Models in Engineering and Management Science. Amsterdam: Elsevier Science, publishers B. V., 1988

9 Abraham K. Fuzzy Maths Techniques With Applications Reading: Mass. Addison-wesley Publishing CO. 1986

10 Lou Shibo. Fuzzy Maths, Beijing: Science Press, 1983

11 Wang Peizhuang. On the Fuzzy Aggregation & its Applications, Shanghai: Shanghai Science & Technology Press. 1983