

# Study and Simulation of Emulsion Pump Pressure Controller Based on Fuzzy-immune PID Algorithm

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**Abstract.** Combining the principle of immune feedback system and the theory of fuzzy control, the fuzzy-immune PID controller is proposed to adapt the characteristic of emulsion pump feeding liquid loop, such as large inertia, nonlinearity and pure time-delay. The system has the advantage of higher self-adaptive ability through real time modifying PID parameter under fuzzy control rulers. The simulation result shows that the controller has effective response and robust feature.

**Keywords:** immune feed; fuzzy PID control; Emulsion pump; self-adaptive ability

## 1. Introduction

As the auxiliary equipment of hydraulic supports, emulsion pump provides stable pressure for supports according to the dynamic variety of pipeline pressure when they are fallen down, risen up and moved. The emulsion pump is controlled by conventional PID controller to supply steady pressure for feeding liquid system. Although general PID control has the advantage of simple construction and easy to be realized, it can not meet the requirement of support liquid supply due to the movement of support has no rule and liquid providing system module has pure time-delay second-order large inertia link. For improving pressure stability of hydraulic system, fuzzy-immune PID is adopted in the paper to achieve real time control of emulsion pump.

## 2. Fuzzy-immune PID Control

### A. Conventional PID control

In virtue of its brief arithmetic, nice robust and high reliability, PID control algorithm is widely used in process control and motion control as one of the earliest developed control strategy. As shown in Fig.1, it is a simple and effective control algorithm based on error information estimate.

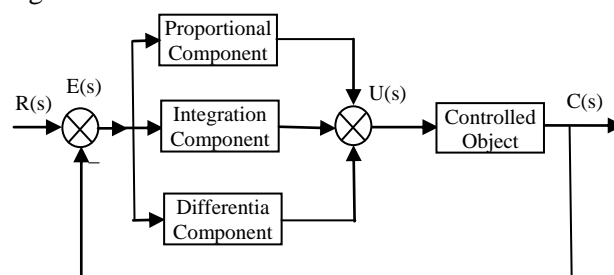


Figure.1 Conventional PID controller structure diagram

The digital PID control rule is:

$$u(k) = K_p \left[ e(k) + \frac{1}{T_i} \sum_{i=0}^k e(i) + T_d \frac{e(k) - e(k-1)}{T} \right] \quad (1)$$

In Eq.(1),  $u(k)$ ,  $e(k)$  is the  $k$ th order sample value of controller output(controlled variable) and input(error) respectively;  $K_p$  is proportional gain;  $T_i$ ,  $T_d$  is integration time constant and differentiating time constant;  $T$  is sample periods

From above equation we can draw a conclusion that the conventional PID don't have adaptability without the ability of real time modifying system parameter.

### B. Fuzzy-immune PID control

Being the body defense system towards biological interference, immune system can produce corresponding antibody for foreign invasion antigen. After the combining of antibody and antigen, a serial of reactions will happen to eliminate the influence of antigen. After antigen intruding body, the information is transferred to  $T$  cell (including auxiliary cell  $T_h$  and suppressor cell  $T_s$ , both are lymphocyte). Then the B cell is activated to generate antibody to remove antigen. The lymphocyte play different roles in each stage: during the beginning of immune reaction  $T_h$  cell eliminate antigen as soon as possible while  $T_s$  cell assures the stability of system at the end of reaction.

The immune PID controller is brought forward based on above immune feedback theory: on the assumption that the number of the  $k$ th order generation antigen is  $\varepsilon(k)$ , the output of  $T_h$  produced by antigen is the  $T_h(k)$ , the influence of  $T_s$  cell to B cell is  $T_s(k)$ , so the total stimulation received by B cell is:

$$S(k) = T_H(k) - T_S(k) \tag{2}$$

The feedback control rule is:

$$u(k) = \frac{K}{T_H(k)} (1 - \eta f(u(k), \Delta u(k))) e(k) = k_{p1} e(k) \tag{3}$$

In Eq.(3),  $K = \frac{T_s(k)}{T_H(k)}$  is for controlling reaction speed,  $\eta = \frac{T_s(k)}{f(s(k), \Delta s(k)) T_s(k)}$  is for controlling stabilization effect,  $f(\cdot)$  is a selected nonlinear function and used for describing stimulation restrain capability of the cell.

Because the immune controller is a nonlinear controller, its expression could be:

$$u(k) = k_{p1} e(k) + k_i T \sum_{j=0}^k e(j) + k_d \left[ \frac{e(k) - e(k-1)}{T} \right] \tag{4}$$

The PID recursion equation is:

$$u(k) = u(k-1) + k_{p1} [e(k) - e(k-1)] + k_i T e(k) + k_d \left[ \frac{e(k) - 2e(k-1) + e(k-2)}{T} \right] \tag{5}$$

The nonlinear function  $f(\cdot)$  can be approached by using fuzzy rules. Each input variable will be transformed to positive (P) and negative (N) by the rules while each output variable will be positive (P), zero (Z) and negative (N).

The fuzzy rules are designed according to the principle: "the more stimulation the cell receives, the lower restrain capabilities; vice versa".

The proportional gain factor can be determined by controller on the basis of immune theory to fit the requirement of error towards output. The integral factor and differential factor can be adjusted with fuzzy theory real-timely to meet the demand of control parameter under different error and error variety.

Fig.2 shows the fuzzy-immune PID control structure diagrams

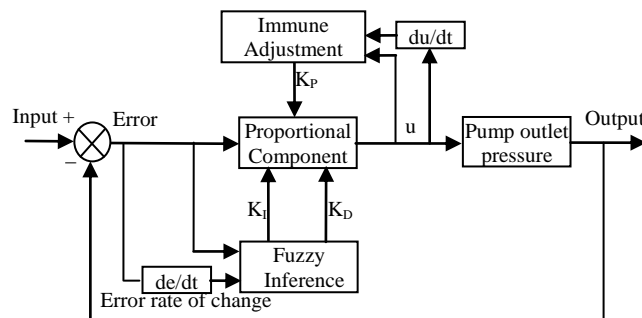


Figure.2 Fuzzy-immune PID controller structure diagram

Seven fuzzy sets(including positive big, positive middle, positive small, zero, negative small, negative middle, negative big) are selected to transform the output variable  $\Delta k_i, \Delta k_d$  into fuzzy variable. Established from expert knowledge and designer's experience, the fuzzy rule of integral factor and differential factor is shown in The table 1 and table 2 respectively.

TABLE I Fuzzy rules of integral factor

| $e$ | $\Delta e$ |    |    |    |    |    |    |
|-----|------------|----|----|----|----|----|----|
|     | NB         | NM | NS | Z  | PS | PM | PB |
| NB  | NB         | NB | NM | NM | NM | Z  | Z  |
| NM  | NB         | NB | NS | NS | NS | Z  | Z  |
| NS  | NB         | NM | NS | NS | Z  | PS | PM |
| Z   | NM         | NS | NS | Z  | PS | PM | PM |
| PS  | NM         | NS | Z  | PS | PS | PM | PM |
| PM  | Z          | Z  | PS | PS | PS | PM | PB |
| PB  | Z          | Z  | PS | PM | PM | PB | PB |

TABLE II Fuzzy rules of differential factor

| $e$ | $\Delta e$ |    |    |    |    |    |    |
|-----|------------|----|----|----|----|----|----|
|     | NB         | NM | NS | Z  | PS | PM | PB |
| NB  | PS         | NS | NB | NB | NB | NM | PS |
| NM  | PS         | NS | NB | NM | NM | NS | Z  |
| NS  | Z          | NS | NM | NM | NS | NS | Z  |
| Z   | Z          | NS | NS | NS | NS | NS | Z  |
| PS  | Z          | Z  | Z  | Z  | Z  | Z  | Z  |
| PM  | PB         | NS | PS | PS | PS | PS | PB |
| PB  | PB         | PM | PM | PM | PS | PS | PB |

### 3. Stimulation analysis

The emulsion pump feeding liquid loop has the feature of large inertia , nonlinearity and pure time-delay. The system can be regarded as being composed of Inertial first-order link, proportion link and time-delay link with the mathematical model as below:

$$G(s) = \frac{K}{(1+T_1s)(1+T_2s)} e^{-\tau s} \quad (6)$$

In Eq. (6) ,  $T_1$  is the time constant of feeding liquid system while  $T_2$  of driver system,  $\tau$  of the time-delay link and  $K$  of system total gain.

These parameters are settled as follow:  $K=0.9$ ,  $T_1=10$ ,  $T_2=12$ ,  $\tau=60s$ ; the input signal is  $1\text{sign}(\sin(2\pi t))$ . For testing the robust of controller, interference is added in the 600th sample point. The tracing result shown in Fig.3 and Fig.4 prove that the immune PID controller has good control effect and high robust.

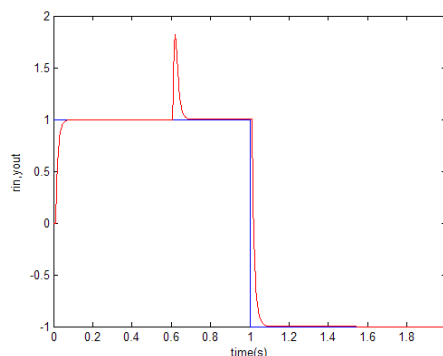


Figure.3 Square-wave tracing of Fuzzy-immune PID controller

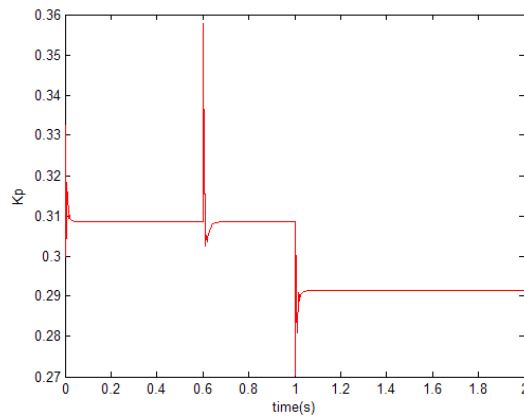


Figure.4 Proportion gain variety of Fuzzy-immune PID controller

## 4. Conclusion

Combining the advantages of immune feedback and fuzzy PID control, the Fuzzy-immune PID controller achieves self-tuning of system parameters. The simulation curve shows that this method has the virtue of fast response and short adjust time and can meet the pressure stability requirement of emulsion pump hydraulic loop and improve the insensitivity to disturbance and system robust.

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