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VALVE BARREL POSITION CONTROL BASED ON SELF-TUNING FUZZY PID WITH PARTICLE SWARM OPTIMIZATION

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Abstract- ***This paper introduced the self-tuning fuzzy PID controller based on particle swarm optimization which aims to gain more precise control over the position of pneumatic proportional valve barrel, where particle swarm works to optimize the membership function, fuzzy rule and PID parameter in fuzzy control. The study fruits also include online optimization of the self-tuning fuzzy PID controller parameters. Comparing to the conventional control methodology, The self-tuning fuzzy PID controller with PSO optimization is proven to show better precision, dynamic performance index and more rapid tracking performance and robustness. To this end, step response was used to compare and analyze the results from the PSO algorithm optimization, providing a pragmatic method of better comprehensive performance for PID parameter optimization.***

Index terms***:*** **Position Control; Particle Swarm Optimization; Fuzzy PID**

I. INTRODUCTION

With air as working medium, pneumatic proportional valve barrel conveys energy and signals. Controlling signals via the proportional valve barrel has been widely used in manufacturing process automation. Owing to its environmentally friendly, safe, convenient, and economic features, the pneumatic proportional valve delivers good performance in modern control field, microelectronic and computer technology[1]. In recent years, research work on pneumatic proportional valve barrel has surged. Various types of control including PID, non-linear PID, optimal, robustness, parameter self-tuning, fuzzy control PID and fuzzy neural network, all being applied to the pneumatic proportional valve barrel[2-6]. But most control methods obtain no effective optimization. Conventional control method can hardly obtain ideal effects due to the presence of easy compression of air in the barrel, non-linearity between input and output, friction of cylinder and parameters of the valve subjected to temperature and pressure. To tackle these issues, particle swarm optimization is then taken to get fuzzy PID to enable a more precise, rapid and stable control.

II. PNEUMATIC PROPORTIONAL VALVE MODEL

The experiment system composes mainly of FESTO Company's DGPL-25-400-PPV-A-B rodless cylinder, MPYE-5-1/4-010B three-position five-path proportional valve, MLO-POT-500-TLF displacement transducer，A/D and D/A convertor commonly used in HY-6070 along with computers, as shown in Figure 1.

Basic principle of the system: A computer collects signal Uf from displacement transducer through A/D module and compares it to set signal (input voltage signal) Ue, if Ue-Uf >0, the air passage of proportional valve on the left opens, followed by air pressure of the left cavity that rises to push right the cylinder piston. This is accompanied by an increasing signal Uf of displacement transducer, while deviation ∆U of Ue-Uf decreases accordingly till it reaches zero. Conversely, when the signal Uf of the setpoint (input voltage signal) displacement sensor, Ue <Uf, ie Ue-Uf = ∆U <0, an adjustment procedure in contrast to the above may help reduce ∆U down to zero. When stability is reached, namely, Uf=Ue = ky，∆U=0. k = scale factor, y = displacement of cylinder piston. Positioning control of input signal Ue and displacement of piston Y is realized[7].

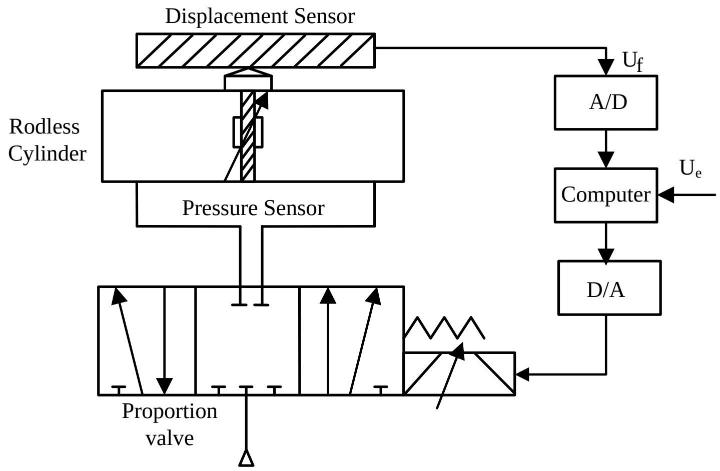

Figure 1. System Structure of Proportional Valve Barrel

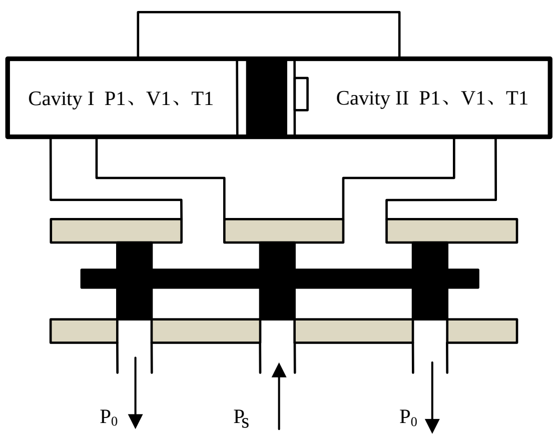

Figure 2. Diagram of Proportional Valve Barrel

Assumptions inferred from Figure2: (1) the medium of pneumatic proportional valve barrel is ideal gas, namely, PV=MRT; (2) constant set pressure and temperature, namely, PS and TS are constant; (3) the balanced gas of pneumatic proportional barrel and equal parameters in all cavities; (5) changes of all parameters during system dynamic change are minuteness.

The open-loop transfer function of pneumatic proportional valve barrel was sorted out by calculation

$$G(s)=\frac{Kv}{s(s^2+\frac{2\zeta_n}{\omega_n}s+1)}$$

In the experiment, air pressure is 0.6Mpa, load is 150N, cylinder lift is 500mm and piston diameter is 25mm. That is: Kv=8.2, ζn=0.2, ωn=39.5 Therefore:

$$G(s)=\frac{12794.05}{s(s^2+15.8s+1560.25)}$$

III. FUZZY CONTROLLER DESIGN BASED ON PARTICLE SWARM OPTIMIZATION

Fuzzy control is an advanced control technology based on language rule and fuzzy inference, also being one of the most important and active branches in intelligent control field. Fuzzy control boasts strong robustness and the capacity to control complex objects which are hard for modeling needing no precise model of controlled object, so it is widely applied in various industries such as manufacturing, agriculture, national defense and medicine.

Selection of fuzzy controller depends on system input including system error (E) and error change rate (EC), so two-dimensional fuzzy controller was chose n due to its control effect and good stability to reduce overshooting and vibration of system. Categorize after E and EC discretizing within certain range. Generally it's divided into 6 types to reduce control difficulty and complexity so as to ensure fuzzy set to better cover its domain of discourse and avoid runaway. Discriminate E, EC and change of controlled quantity by three fuzzy concepts of "big", "medium" and "small", and divide them into 7 values: Plus Big (PB), Plus Medium (PM), Plus Small (PS), Zero (0), Negative Small (NS), Negative Medium (NM) and Negative Big (NG) [8-12]. See Table 1 for fuzzy control rule compiling based on Table 1

Table 1. Fuzzy Control Rule Table

U		E						
		NB	NM	NS	0	PS	PM	PB
EC	NB	NB	NM	NM	NS	NS	0	PS
	NM	NB	NM	NS	NS	0	PS	PM
	NS	NM	NM	NS	NS	0	PS	PS
	0	NM	NM	NS	0	PS	PS	PM
	PS	NB	NS	0	PS	PS	PM	PB
	PM	NB	NS	0	PS	PM	PM	PB
	PB	NB	NS	PS	PM	PM	PB	PB

Initialize a group of particles with no volume and mass at random, view every particle as a feasible solution after optimization which is decided by the set function. Particles move within the space of feasible solution, one speed decides its direction and distance chase the current optimal particle to search the optimal solution gradually. Meanwhile a particle of each generation has two optimal solutions: optimal solution searched by one particle so far, and another one searched by the whole particle swarm.

Assuming: a particle swarm formed by M particles in a D-dimension search space, particle's state in time t is as follows:

Position:

$$x_i^t = (x_{i1}^t, x_{i2}^t, \cdots, x_{id}^t)^T, \ x_{id}^t \in [ld, ud],$$

Speed:

$$v_i^t = (v_{i1}^t, v_{i2}^t, \cdots, v_{id}^t)^T \ \ v_{id}^t \in [v_{\min}, v_{\max}];$$

Individual optimal position:

$$p_i^t = (p_{i1}^t, p_{i2}^t, \cdots, p_{iD}^t)^T;$$

Global optimal position:

$$p_g^t = (p_{g1}^t, p_{g2}^t, \cdots, p_{gD}^t)^T,$$

including

$$1 \le d \le D, 1 \le i \le M.$$

Then position and speed of particle in time t+1 changes to:

$$v_{id}^{t+1} = \omega v_{id}^t + c_1 r_1 (p_{id}^t - x_{id}^t) + c_2 r_2 (p_{gd}^t - x_{id}^t)$$

$$x_{id}^{t+1} = x_{id}^t + v_{id}^{t+1}$$

r1 and r2 are random numbers within [0,1], c1 and c2 are learning factors, also called accelerated factor, usually c1=c2=2.

ω is inertia weight, whose value decides the particle's inheriting of current speed.

The first part is inheriting from previous speed, keeping on inertia motion relying on particle's own speed;

The second part is the cognition part of particle, i.e. particle's thought on itself. Integrate particle's own path and experience then to make further decision, which is a self-learning process of particles.

The third part is the social part, namely, information sharing and cooperation between a particle and other particles. Implementation steps are as follows [13,14]:

Step 1: Initiate population's position and speed; Step 2: Calculate particle's objective function value; Step 3: For each particle, compare the fitness value of optimal position P having been found by particles so far and that of themselves, choose the better one as the optimal position; Step 4: For each particle, compare the fitness value of global optimal position P having been found by particles so far and that of themselves, choose the better one as the global optimal position; Step 6: refresh the speed and position of particles based on formula (3), (4); Step 7: If the above calculation cannot meet the requirement, go back to Step 2 [13, 14].

Key of particle swarm optimization is the setting of objective function. Adopt ITAE method to use particle swarm to optimize objective function. Optimize dynamic and static index of the system[15,16].

$$J_{itac} = \int_{0}^{+\infty} t\,|\,e(t)\,|dt \quad (1)$$

In the formula, e(t) is error. PID algorithm utilizes error's ratio, integral and differential to form linear combination and controller, and PID regulator input can be described as:

$$U(t) = K_p[e(t) + \frac{1}{T}\int_{0}^{t} e(t)dt + \frac{T_D de(t)}{dt}] \quad (2)$$

In the formula, KP = proportion magnification factor, T = integral time constant, TD = differential time constant; and K1 = KP/KD, KD = KPTD; e(t) is the feedback deflection of the system. The central part of facilitating particle swarm to optimize and set parameters of self-tuning fuzzy PID is to utilize error optimization algorithm, error change rate and the optimal position of θ=[KP, KI, KD], enabling dynamic and static index of PID control to comply with the requirement. The essence is a process for objective function to pursue optimization[17,18].

IV. SIMULATION EXPERIMENT AND RESULTS ANALYSIS

Figure 3 is system editor of fuzzy inference, Figure 4 is membership function curve of input variable (e), Figure 5 is membership function curve of input variable (ec), Figure 6 is membership function curve of output variable (kp), Figure 7 is membership function curve of output variable (ki), Figure 8 is membership function curve of output variable (kd), Figure 9 is the editor window of fuzzy control rules, Figure 10 is graphic of rules observer, Figure 11 is graphic of surface observer (kp), Figure 12 is graphic of surface observer (ki), Figure 13 is graphic of surface observer (kd), Figure 14 is membership function curve of input variable after optimization (e), Figure 14 is membership function curve of input variable after optimization (e), Figure 15 is membership function curve of input variable after optimization (ec), Figure 16 is membership function curve of output variable after optimization (kp), Figure 17 is membership function curve of output variable after optimization (ki), Figure 18 is membership function curve of output variable after optimization (kd). Table 2 is control rule table after optimization (kp), Table 3 is control rule table after optimization (ki), Table 4 is control rule table after optimization (kd). Figure 19 is fuzzy PID system simulation model after optimization, Figure 20 is fuzzy PID simulation oscillogram of fuzzy control and simulation model after optimization. From the result, self-tuning fuzzy controller optimized by particle swarm is proven to own stable and rapid control performance. Conventional PID simulation results show: larger system overshoot, briefly longer rising time and regulation time[19]. Simulation results of fuzzy PID controller optimized by particle swarm were: shorter rising time and regulation time of simulation model, while simulation result of PSO optimization model overshoot was poor but stable, with longer system recovery time than that of PID control simulation under the influence of step disturbance, Self-tuning fuzzy model optimized by particle swarm has better disturbance -rejection capacity than non-linear typical model. It is shown that the controller is applicable to situation requiring high stability, which is most important in control system. No stability, no system. So PSO optimization result has an advantage in overshoot optimization and wide application in control field.

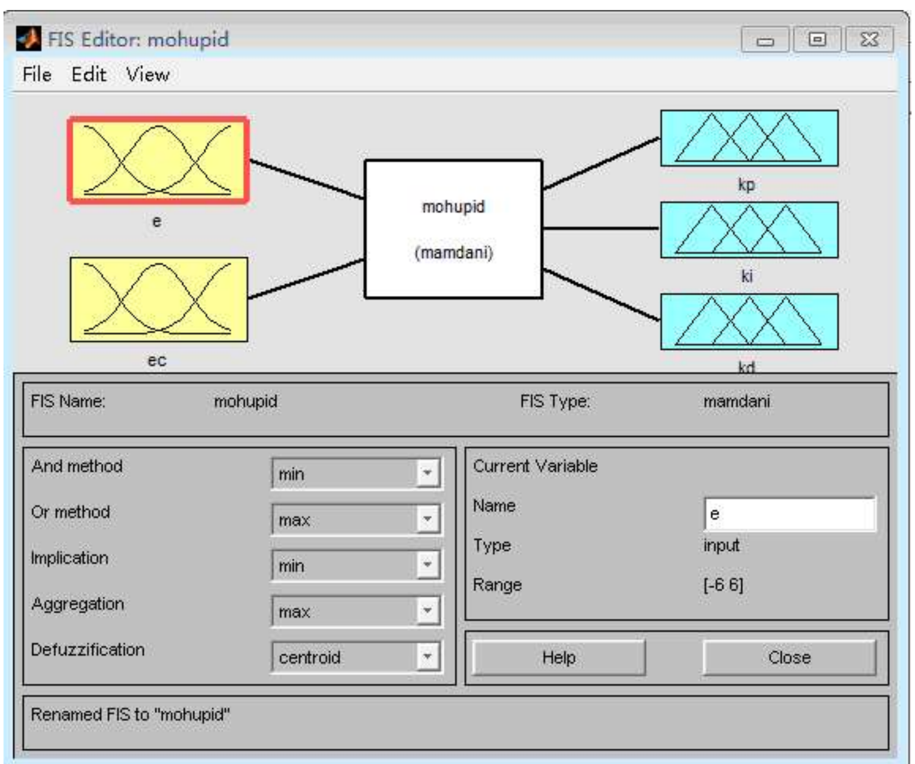

Figure3. System editor of fuzzy inference.

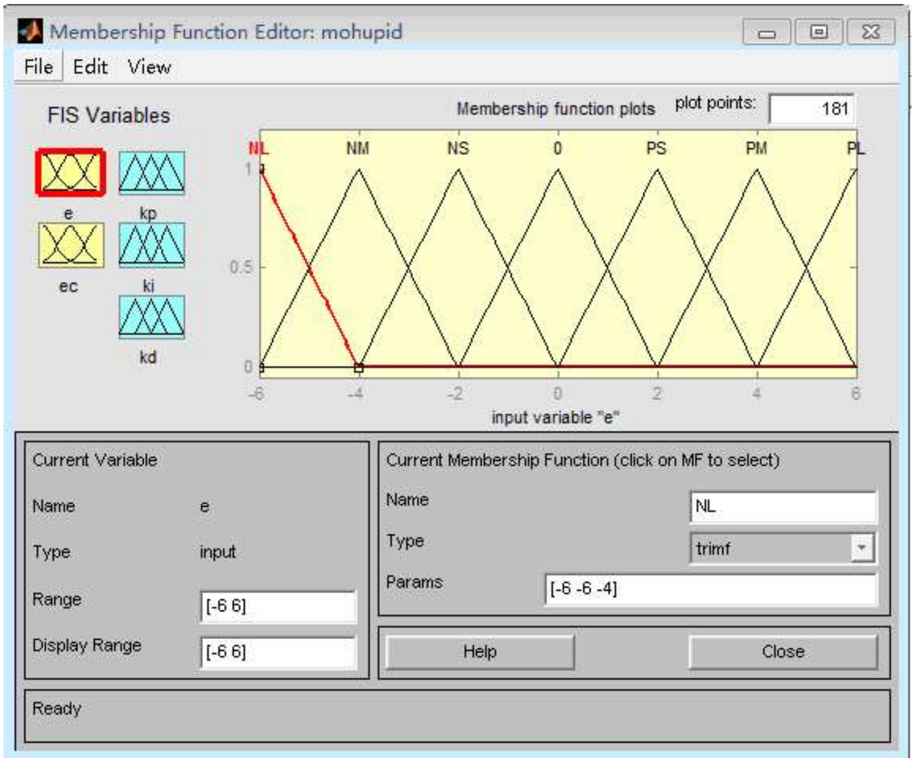

Figure4. Membership function curve of input variable (e)

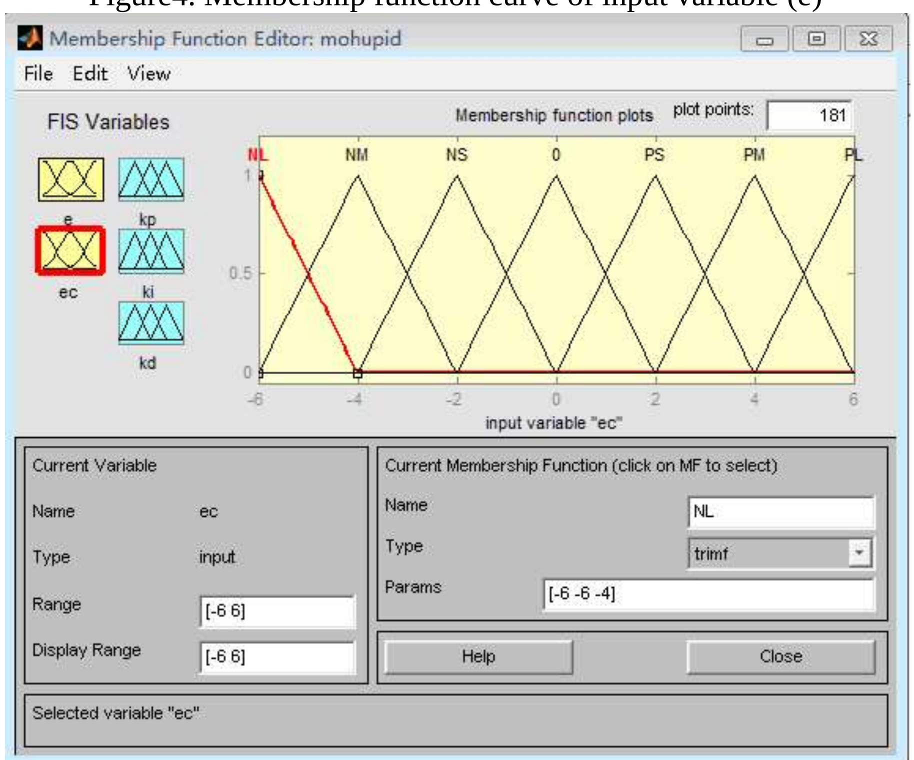

Figure5. Membership function curve of input variable (ec)

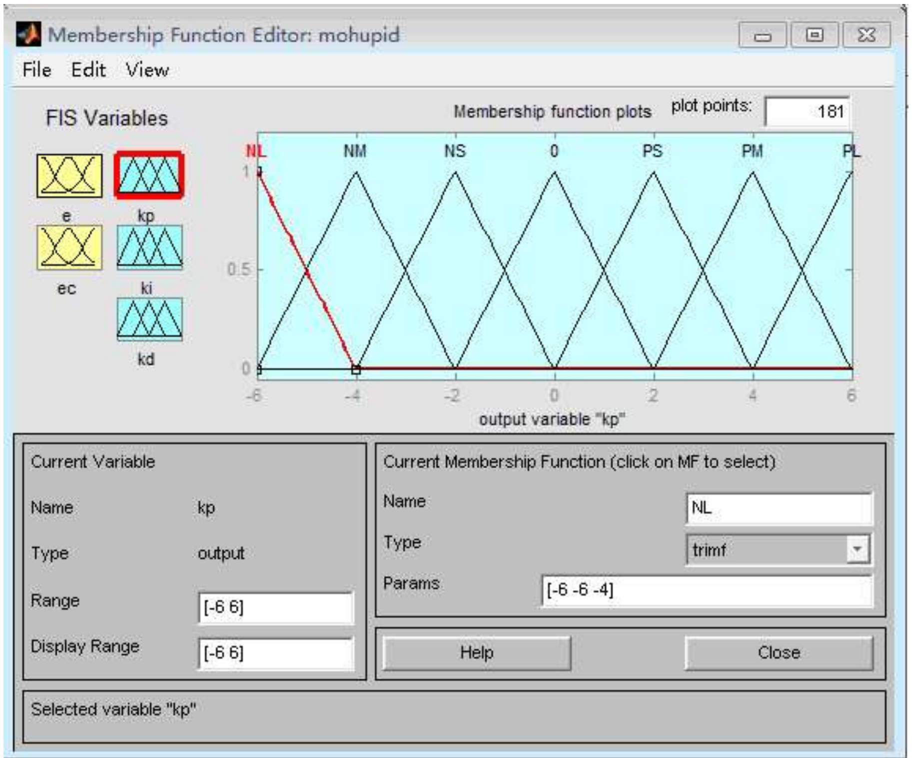

Figure6. Membership function curve of output variable (kp)

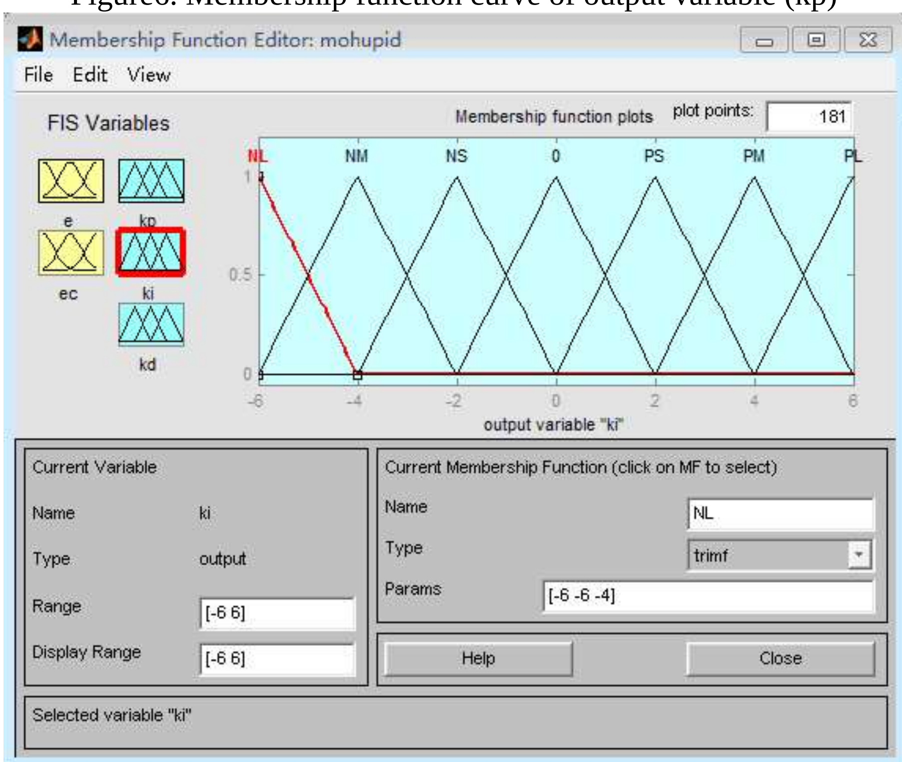

Figure7. Membership function curve of output variable (ki)

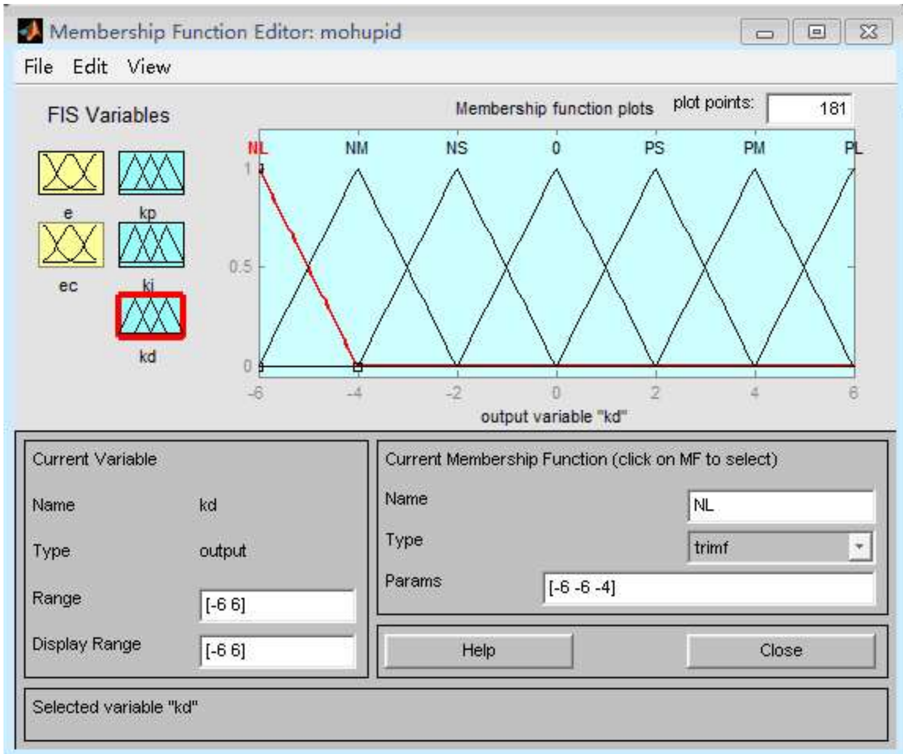

Figure8. Membership function curve of output variable (kd)

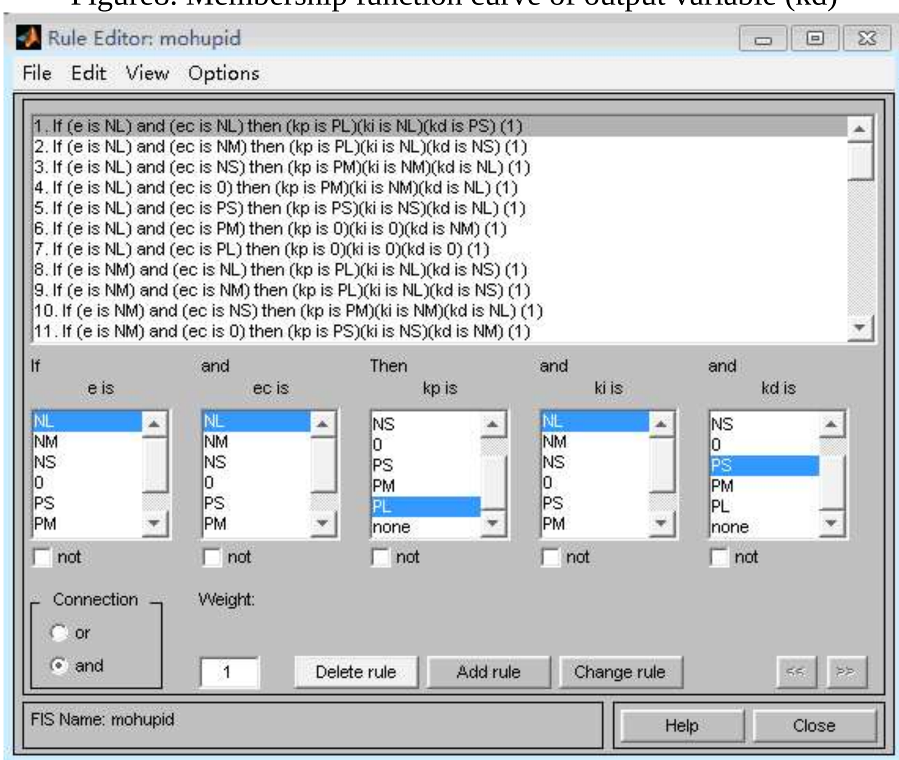

Figure9. The editor window of fuzzy control rules

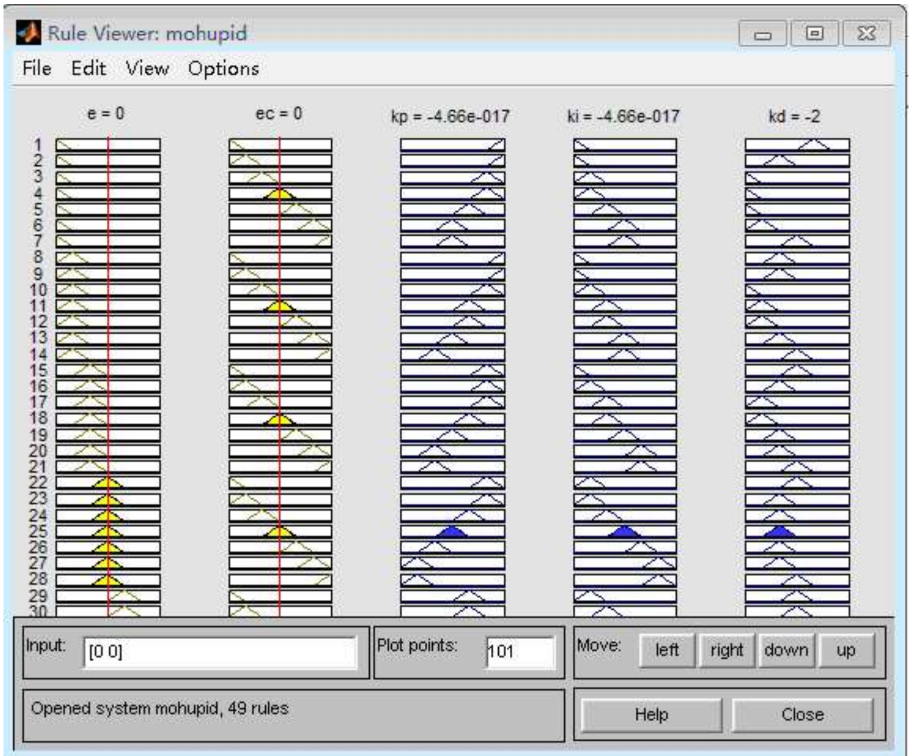

Figure10. Graphic of rules observer

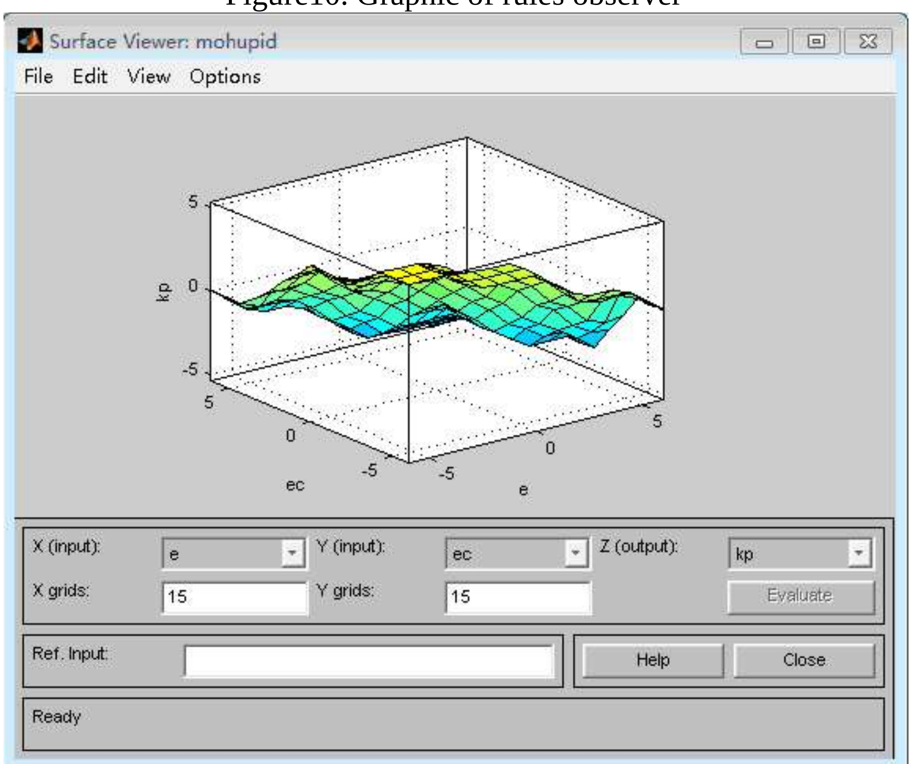

Figure11. Graphic of surface observer (kp)

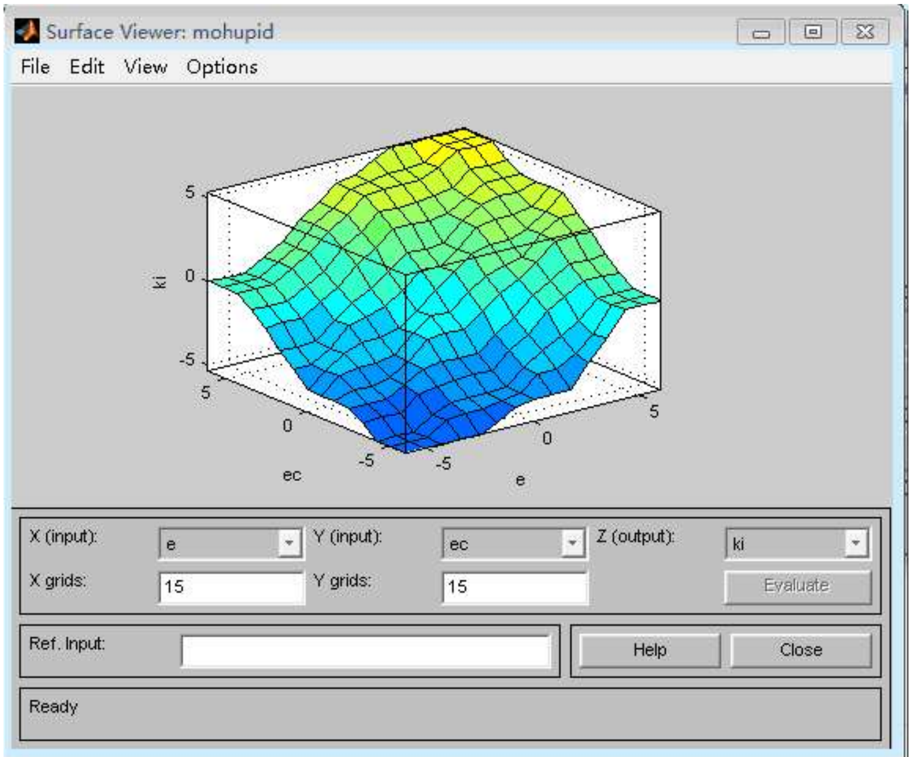

Figure12. Graphic of surface observer (ki)

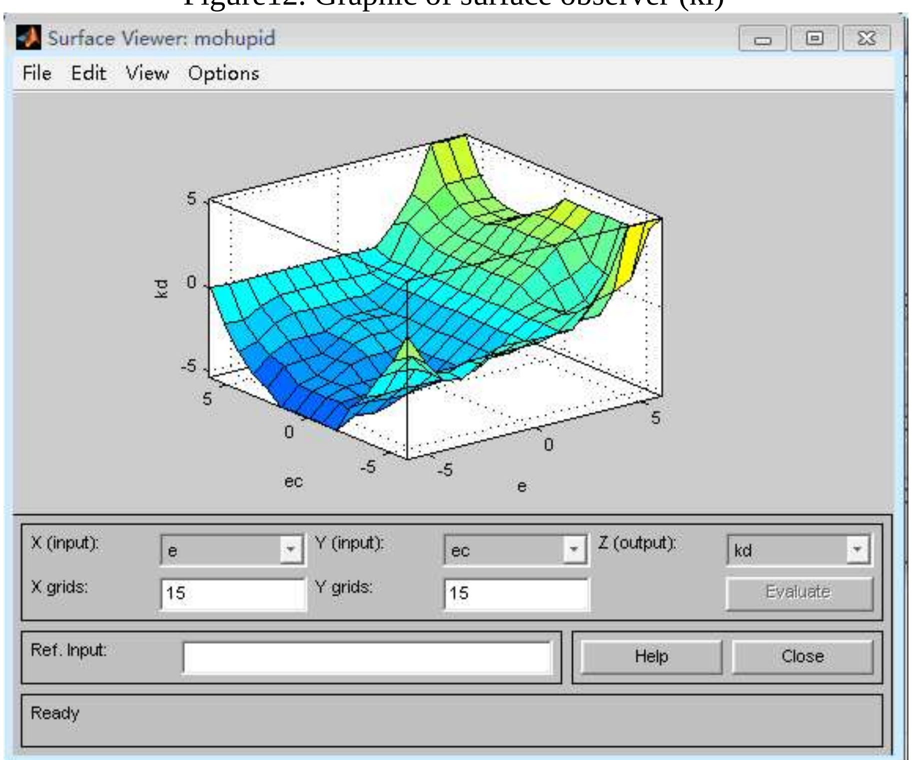

Figure13. Graphic of surface observer (kd)

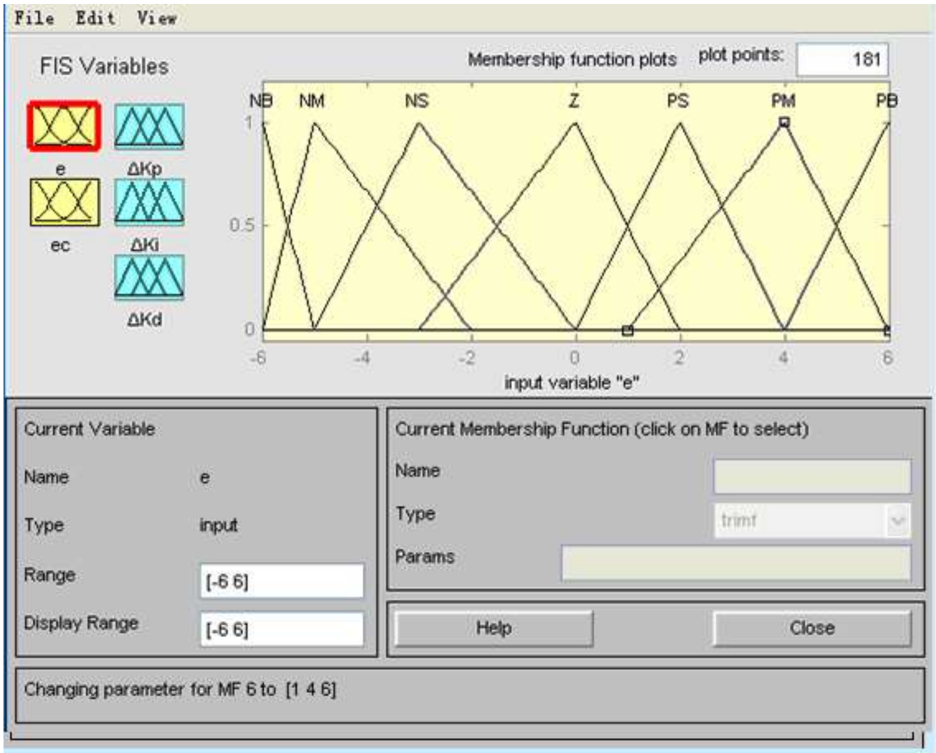

Figure14. Membership function curve of input variable after optimization (e)

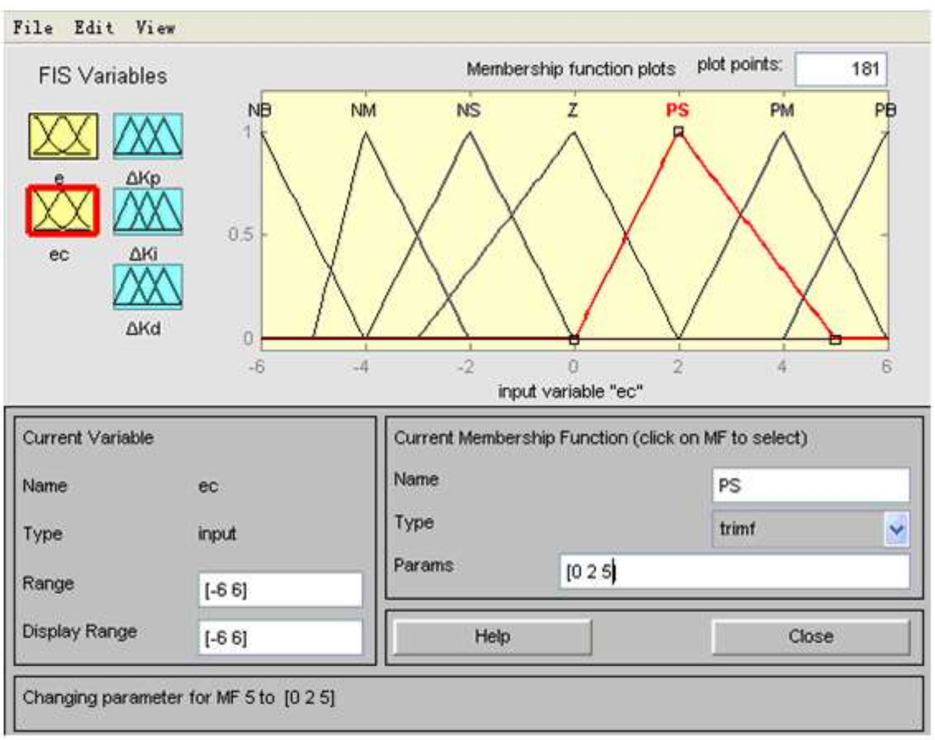

Figure15. Membership function curve of input variable after optimization (ec)

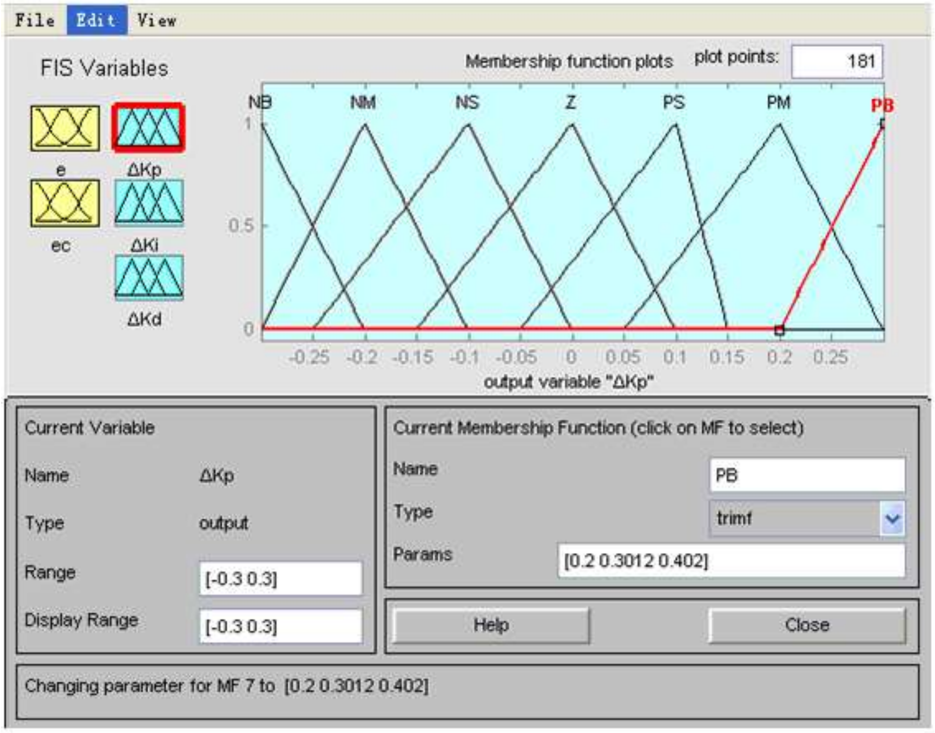

Figure16. Membership function curve of output variable after optimization (kp)

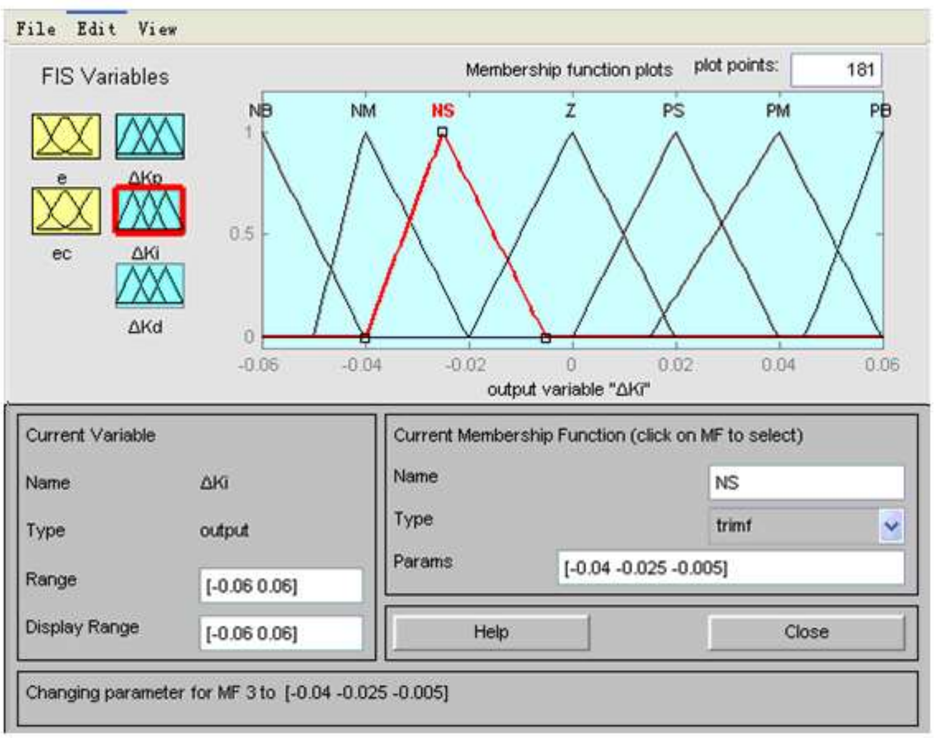

Figure17. Membership function curve of output variable after optimization (ki)

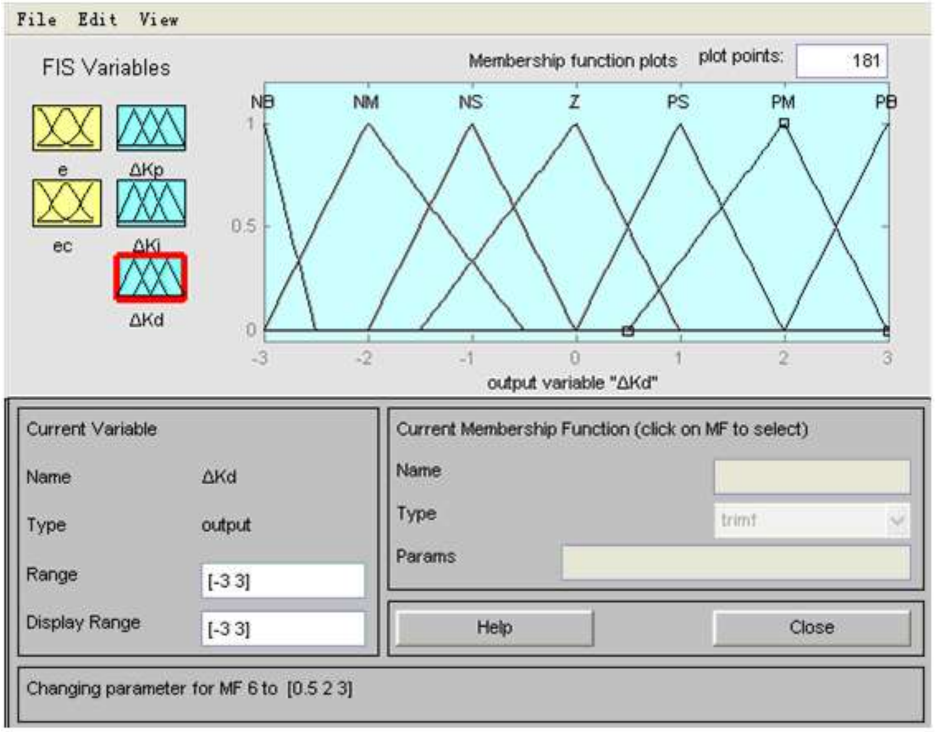

Figure18. Membership function curve of output variable after optimization (kd)

Table 2. Control rule table after optimization (kp)

EC	E						
	NB	NM	NS	Z	PS	PM	PB
NB	NM	NB	NM	NB	PB	PM	NM
NM	Z	PS	PM	NB	PM	NB	NB
NS	NM	NS	PM	PB	PM	PM	NS
Z	NM	PS	PM	PB	PB	NB	Z
PS	NB	Z	PB	PM	PM	PM	NM
PM	PM	NM	PB	NB	NB	PM	NM
PB	PS	PS	NB	NM	PS	Z	NB

Table 3. Control rule table after optimization (ki)

EC	E						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	NB	NB	Z	PS	PM
NM	PB	NM	NB	PM	NB	NS	PB
NS	PB	PN	NM	PS	NS	NB	PB
Z	PB	NB	NS	Z	Z	NM	PM

PS	PS	NB	NB	PB	PM	Z	NB
PM	NB	NB	NB	PM	NM	NS	NB
PB	PM	PM	Z	NS	NB	NB	PM

Table 4. Control rule table after optimization (kd)

EC	E						
	NB	NM	NS	Z	PS	PM	PB
NB	PM	PS	NS	PB	NB	NB	NM
NM	PM	PM	NB	PB	NB	NB	NM
NS	PS	PM	NB	Z	PM	Z	NM
Z	Z	Z	PS	NM	PM	NB	PS
PS	Z	NM	PS	PB	PB	PB	NB
PM	NS	NM	NS	NB	PM	NM	NB
PB	NS	NM	Z	NS	PM	PS	NB

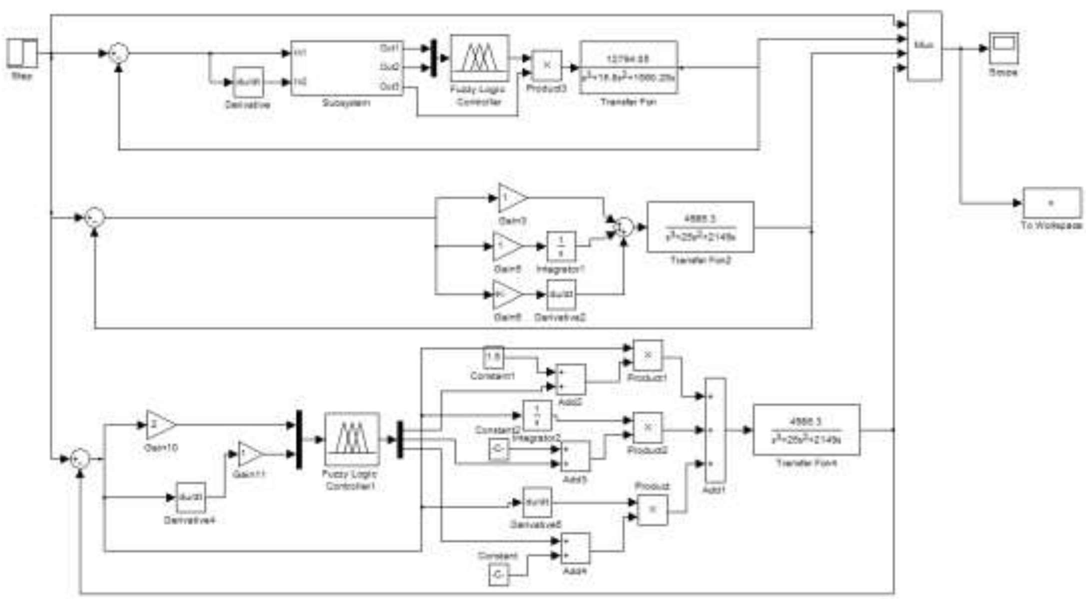

Figure19. Fuzzy PID system simulation model after optimization

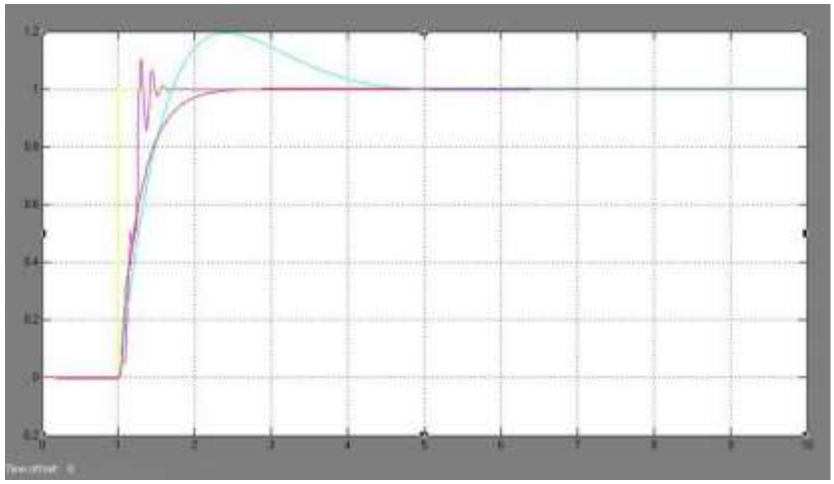

Figure20. fuzzy PID simulation oscillogram of fuzzy control and simulation model after optimization.

V. CONCLUSION

This paper is here concluded by applying the particle swarm optimization to pneumatic proportional valve barrel control system, conducting parameter optimization on E, EC and KP, KI, KD of fuzzy PID controller, which were compared with those of conventional PID simulation results. It is impressive that the dynamic effect of the former is better than regular ones. Fuzzy PID controller makes a feature of speediness, smaller overshoot, stronger robustness and is more applicable to online control and parameter setting of complex objects. The results appeared that particle swarm optimized pneumatic proportional valve barrel enjoyed more advantage than traditional controllers.

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