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Design and Simulation of the Air Compressor Control System

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Abstract: The air compressor plays an extremely important role in the production of air separation. It provides the required specifications of compressed air for the follow-up air separation processes. The air compressor system is a time-varying, delay and nonlinear complex system, so its design is difficult to achieve the on-site production requirements. Using computer simulation software to simulate the system control program has become an integral part of the process of control system design. Simulink blocks in the Matlab simulation software was used to do modeling and simulation calculation of the air compressor control system. Through the comparisons between the more conventional PID control method and fuzzy self-tuning PID control method in the air compressor, the conclusion can be drawn that the fuzzy self-tuning PID control has a stronger anti-disturbance ability, and it can reach a steady state more easily in the system control. This paper can provide certain theoretical rates to the study of air compressor control system. *Copyright © 2012 IFSA.*

Keywords: Air compressor, Control simulation, Fuzzy intelligent control, Conventional PID control, Fuzzy self-tuning PID control.

1. Introduction

The simulation experiment is crucial for the study of control methods. It anal sizes and studies the performance of the control system through the establishment of physical or mathematical models. The simulation of control system has become an integral part of the process of control system design, because simulation is of great importance to the study of control methods. Nowadays, using computer to simulate the control system and research its characteristics has become the main method and way to the study of control methods. Computer simulating ways are convenient, fast and accurate, and they also have the advantages of being good at solving large-scale, difficult and uncertain questions of system stimulation. The simulation software can flexibly and effectively analyze and compare different control strategies of the system, and then selects the optimal control result in a large number of control programs.

The air compressor control system in air separation production is time-varying, delay and nonlinear, thus its model is more complex and it is difficult to establish a precise mathematical model [1]. On the basis of fuzzy set theory and fuzzy language variables and fuzzy inference logic, fuzzy control combined with expert experience, approximately simulate the human reasoning and decision-making process in the actual production [2]. In this way, the design process of control system will not need to be as accurate as the traditional control systems design mathematical model. Using fuzzy control method to design air compressor controller can overcome the difficulty of establishing a precise mathematical model of the air compressor control system.

Matlab is short for Matrix Laboratory, produced by The Math Works, Inc, USA. It is used for algorithm development, data visualization, data analysis, high-level technical computing language of the numeric computation and interactive environment, etc. Simulink module is one of the most important components of the Matlab software [3]. It provides an integrated environment in dynamic system modeling, simulation and comprehensive analysis for scientists. Users can very easily on the computer use Simulink blocks to complete the modeling and simulation of control systems, analysis of the dynamic characteristics of the system. The Simulink blocks in the Matlab simulation software can be used in modeling and simulation of the air compressor control system. Compare the conventional PID control method with fuzzy self-tuning PID control to find out advantages and disadvantages between them, and finally get the optimal program of the air compressor control.

2. Fuzzy Controller Design

The controlling mode of large-scale air separation equipment commonly uses the constant pressure control. And in order to ensure safe and stable operation of the equipment, there are some auxiliary controls, such as add/unload control, preventing surge control, interlock protection control and start/stop control. The most important control parameter of air compressor pressure control system is the air compressor outlet pressure. The regulation effect of outlet pressure directly affects the performance and productivity of equipments. Due to the time-varying characteristics, hysteresis and nonlinearity of air compressor system, the article uses the fuzzy control design method was used in designing air compressor pressure fuzzy controller and fuzzy PID controller in article. Fuzzy control is not dependent on precise mathematical control system description. It leverages the operational experience of the workers, establishes of control rules, expresses these rules using computer language, and designs a device to implement these rules.

The air compressor system is mainly controlled by the on/off control of the motor and the outlet pressure. When the flow or pressure of the air compressor fluctuates, it maintains the stability of the flow or pressure through the adjustment of speed regulation, the inlet and outlet flow and so on. Speed regulation adjustment has the advantages of the widest adjustment range and the best economical efficiency, but it is not that accurate; while the inlet flow adjustment is simple and has a wide-range control and a better economical efficiency. Different adjustment methods can be chosen according to different processes. No matter which method, the control object is the opening of inlet guide vanes. When using constant pressure control, the opening of inlet guide vane can be adjusted through the adjustment of outlet pressure of the air compressor. And when using constant flow control, it can be achieved through the difference (outlet flow) of outlet pressure of the air compressor.

Air compressor fuzzy controller used two-dimensional control structure. The controller program structure is shown in Fig. 1. Input is the error comparison between the actual pressure and the pressure set point and error rate of change, output is the inlet guide vane opening amount. The controller input was discreted and done fuzzy dealing. Establish the corresponding relationship between the discredited values and the fuzzy variables, achieve the transformation of exact amount to the fuzzy variables, design and build air compressor pressure control rules. The value of the output U was got through using the fuzzy toolbox of Matlab, and anti-fuzzy method selected the gravity center method of the area.

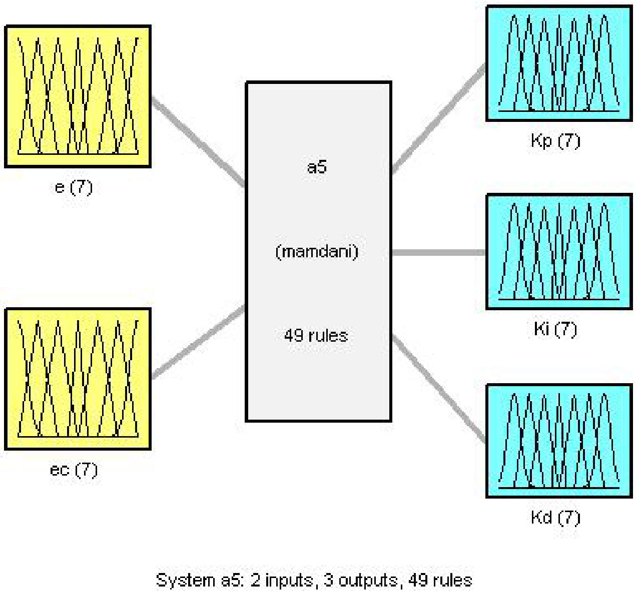

Fig. 1. Fuzzy PID control chart.

The input variables have two parameters: the deviation e and the rate of deviation change ec. The output variable has three parameters: ΔK_p, ΔK_i, ΔK_d. The values of three output parameters can be calculated through the fuzzy inference rules. According to the compressor's operating characteristics and on-site operating experience in the operation. The basic domain of the deviation e can be identified as $\{-0.5,+0.5\}$, the discrete domain can be identified as $X=\{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6\}$, the quantization factor of the deviation is $K_e = 6/0.5 = 12$. The basic domain of the change rate of deviation ec can be identified as $\{-0.3,+0.3\}$, the discrete domain can be identified as $X=\{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6\}$, the quantify factor of the change rate of the deviation is $K_c = 6/0.3 = 20$. The incremental ΔK_p of the coefficient of proportional link K_p, its basic domain can be identified as $\{-0.2,+0.2\}$. The coefficient of the integral part ΔK_i, its basic domain can be identified as $\{-0.1,+0.1\}$. The coefficients of the differential link ΔK_d, its basic domain can be identified as $\{-0.1,+0.1\}$. Discrete domain of the three output variables both are $\{-6,-5,-4,-3,-2,-1,0,1,2,3,4,5,6\}$, then the scale factor of three outputs can be calculated:

$$k_1 = 0.2/6 = 0.03,\quad k_2 = 0.1/0.6 = 0.02,\quad k_3 = 0.1/6 = 0.02$$

Shape of the membership function of the three output variables in its variable both ends selected the low resolution Gaussian membership function, selected the high resolution triangular membership function in other places.

Combined the long-term operational experience of works and expertise's' experience, building the ΔK_p, ΔK_i, ΔK_d fuzzy control rules [4-5] are shown in the following 49 statements:

1) If (e is PB) and (ec is PB) then (ΔK_p is NB)(ΔK_i is PB)(ΔK_d is PB)

2) If (e is PB) and (ec is PM) then (ΔK_p is NB)(ΔK_i is PB)(ΔK_d is PB)

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48) If (e is NB) and (ec is NM) then (ΔK_p is PB)(ΔK_i is NB)(ΔK_d is NS)

49) If (e is NB) and (ec is NB) then (ΔK_p is PB)(ΔK_i is NB)(ΔK_d is PS)

3. Fuzzy Intelligent Control of the Simulation Analysis

It is difficult to establish a precise mathematical model for the air compressor system due to its complexity. So the air compressor system was simplified as a second-order system $k/(T_1 s+1)(T_2 s+1)$, where T_1, T_2 denote constants, and k denotes the amplification. Giving different parameter values to k, T_1 and T_2. Then analyzed and compared the simulation results, the optimal control scheme can be found out. When $k=3$, $T_1=1$, $T_2=1/4$, a simulation framework of fuzzy PID control could be established as Fig. 2.

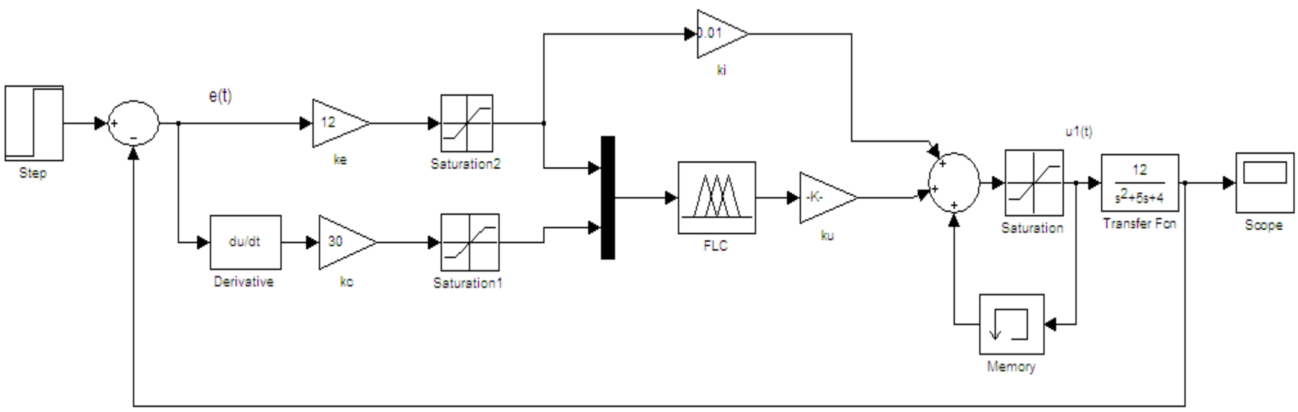

Fig. 2. Simulation framework of fuzzy PID control.

In Fig. 2, FLC is the rule table of fuzzy control done through off-line design; it can also be obtained by Fuzzy Tool through on-line inference. The two parameters inputted to the controller have the same upper and lower limits, they are 6 and -6, and the upper and lower limits of the control signal are respectively 1 and 0. Integral coefficient K_i can eliminate the static error of the system, the input domain of the integrator can be determined, it is [-6, 6]. Order the integral $u_i(t)=6\times 1\%=0.06$, K_i=0.01.

Using synthetical inference mechanism determined the matrix table of the PID fuzzy control, according to the assigned table of fuzzy subset membership degree of E, EC, ΔK_p, ΔK_i, ΔK_d and their control model. When the controller was running online, first it collected the sample signals, then it did the processing, table look-up and operations according to the design, and got the ultimate control quantity, finally it finished the online self-correction of the PID parameters. The parameter values of the three links of the conventional PID can be set by Ziegler-Nichols' critical Proportioning Method [6] they were K_p = 6.3, K_i = 1.2 and K_d = 0.35. By using the Simulink blocks of Matlab, a block diagram of the simulation model of fuzzy self-tuning PID control can be established, which is shown in Fig. 3.

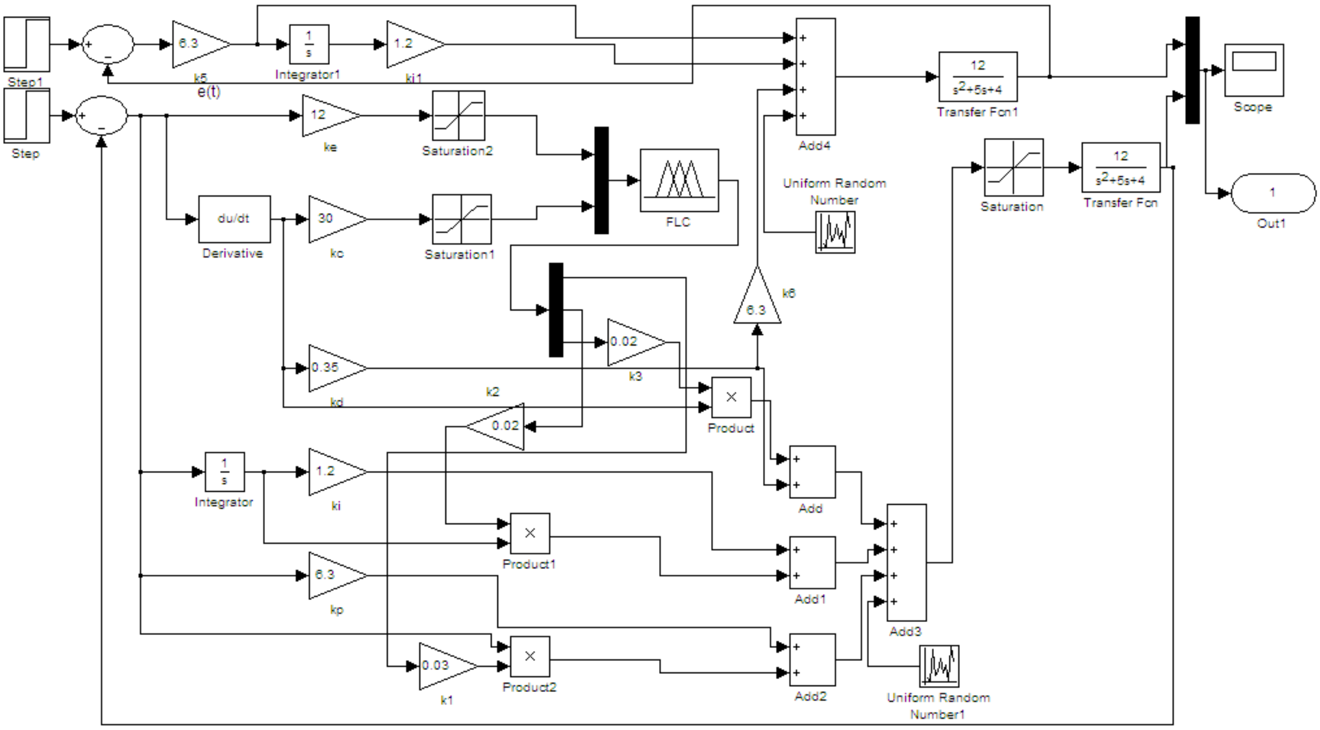

Fig. 3. Block diagram of the simulation model of fuzzy self-tuning PID control.

In addition to the fuzzy self-tuning PID simulation block diagram in Fig. 3, there is a conventional PID simulation block diagram. Order the magnitude of the step input signal equal to 1, when there was no interference signals, the step response curve of the two controls is shown in Fig. 4. When the real-time random noise signals are added, the step response curve of the two controls is shown in Fig. 5.

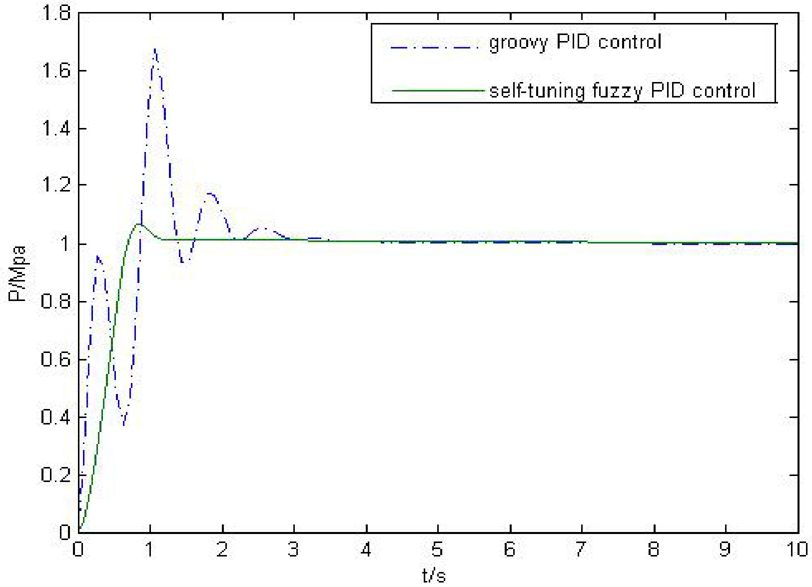

Fig. 4. Simulation curve of the step response without the interference signals.

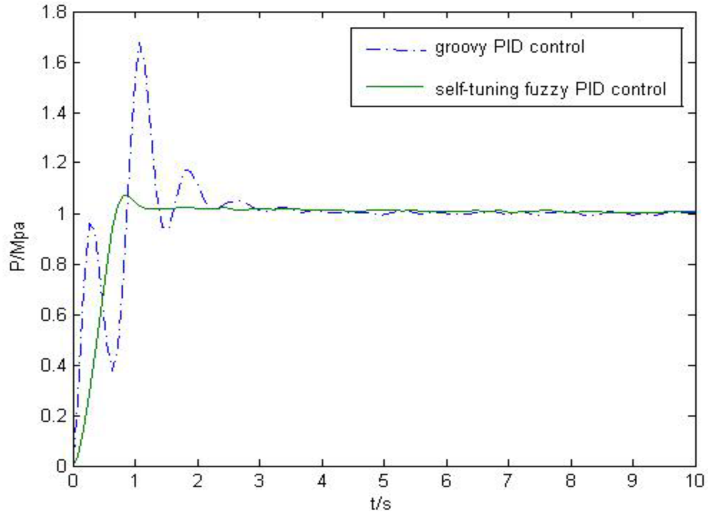

Fig. 5. Simulation curve with interference of real-time random noise signals.

From Fig. 4 and Fig. 5, it can be seen that compared with the conventional PID control, fuzzy self-tuning PID control has the advantages of shorter time to achieve stable, smaller overshoot and significant improvement of the performance of the controlled system. When added real-time random noises, the volatility of fuzzy self-tuning PID control was very slight, that showed it had a very strong anti-interference ability.

When $k=3$, $T_1=1/3$, $T_2=1$, using Z-N critical Proportioning Method, the result is K_p =1.6, K_i =3.6, K_d =0.96 through repeating simulation experiments. After Adding random noise signals, building the simulation block diagram, which is shown in Fig. 6, set the simulation time 90s, a simulation curve with real-time random interference signal can be got, shown in Fig. 7.

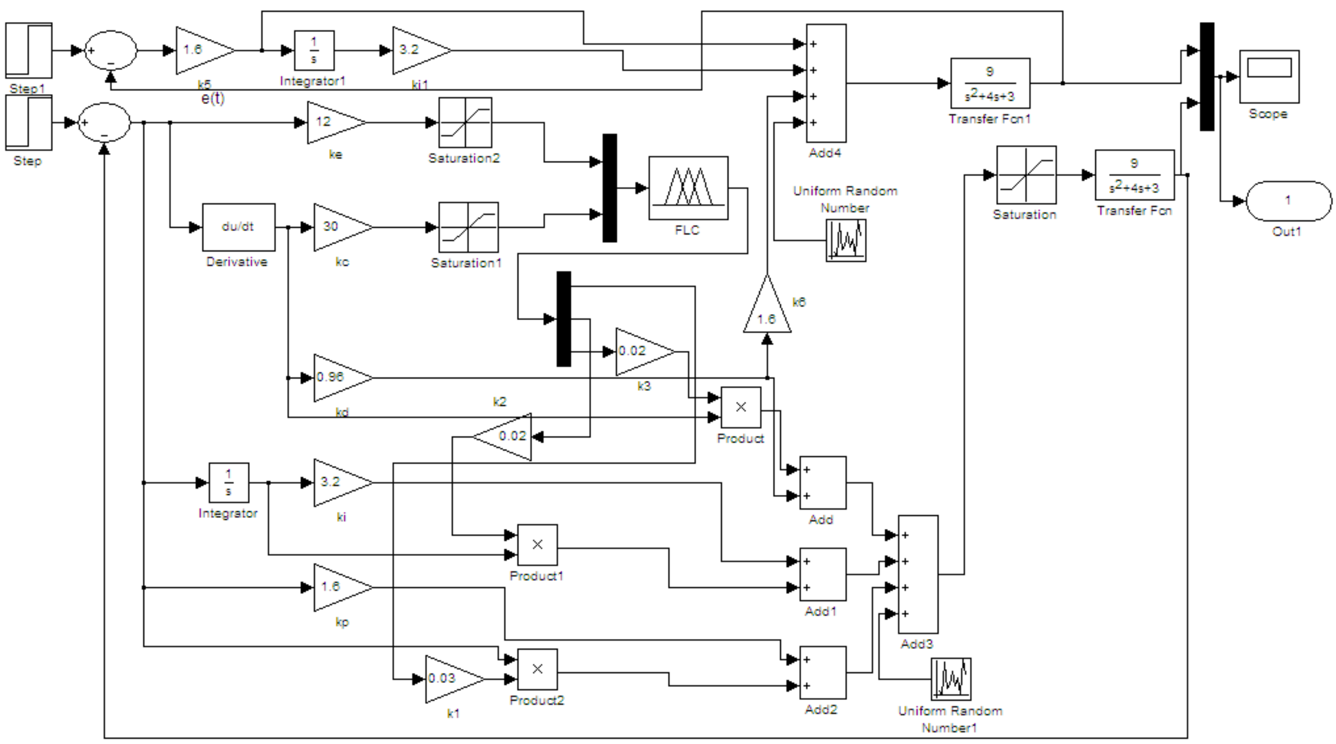

Fig. 6. Simulation model of fuzzy self-tuning PID control with real-time random noises.

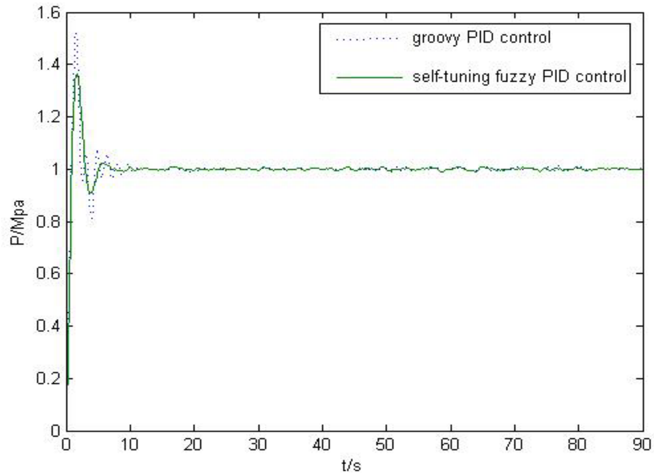

Fig. 7. Simulation curve with real-time random noises.

Fig. 7 showed that when using fuzzy self-tuning PID control system, the system can achieve stability in a shorter time, and its overshoot was very small, the control performance was superior to conventional PID control. Under the simulation diagram in Fig. 6, the existing real-time random noises was retained, and replaced the step signal for the pulse sequence signal, which was characterized by an amplitude of the 20s cycle, pulse width of 1, the simulation curve is in Fig. 8. It can be seen from Fig. 8: Fuzzy Self-tuning PID control has a stronger anti-disturbance capacity, the system controlled by it can reach a steady state more easily. This method has been successfully used in the control of the air compressor system, which has a certain degree of practical significance.

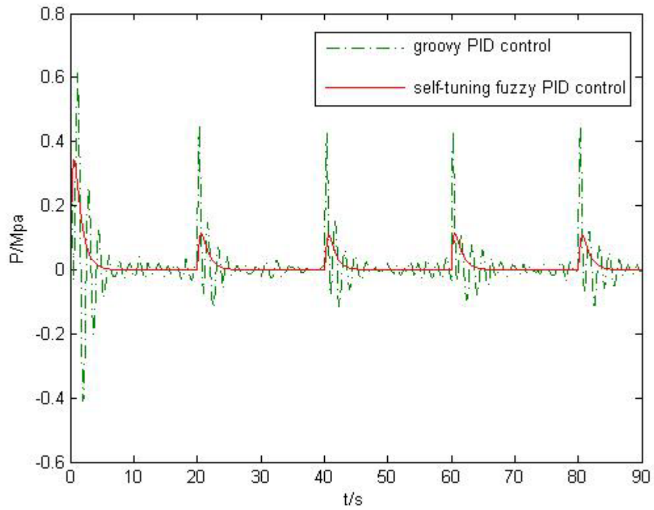

Fig. 8. Response curve of the pulse sequence signal with real-time random noises.

4. Conclusions

In this paper, the author established the simulation model block of the air compressor system, and did some simulation experiments of fuzzy PID control and fuzzy self-tuning PID. The simulation results showed that no matter without interference or with real-time random interference, fuzzy self-tuning PID control was superior, which provided important theoretical basis for the on-site control of the air compressor system.

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