Computer Life (CPL) ISSN: 1819-4818
DELIVERING QUALITY SCIENCE TO THE WORLD

Research on Pressure Control of Static Pressure Test Platform for Aerospace Fluid Connectors

Min Wan, Yixiao Feng

School of mechanical and electrical engineering, Southwest Petroleum University, Chengdu 610500, China

---

Abstract: Aerospace fluid connector is an important part of servo control system of aerospace equipment. High-quality fluid connectors are a prerequisite for the successful launch of space equipment. Static pressure test is an important part of fluid connector quality testing. Aim at static pressure test of Aerospace fluid connector, this article designs and introduces the pressure control circuit of static pressure test and the pressure control method of the circuit, research and design variable universe fuzzy PID controller, finally, the application of variable domain fuzzy PID controller in pressure control of static pressure test is simulated and compared with the traditional PID controller and fuzzy PID controller at last. The simulation results show that the steady state error of the variable domain fuzzy PID controller is small, the control pressure rises steadily, and the anti-interference ability is strong, the advantages of variable universe fuzzy PID control are verified, which verifies the advantage of the variable domain fuzzy PID control and can meet the static pressure test requirements of the aerospace fluid connector.
Keywords: Fluid connector; Static pressure test platform; hydraulic circuit; pressure control; variable universe fuzzy PID control.

---

1. INTRODUCTION

At present, the military industry, special materials, energy industry and other industries use a large number of fluid connectors, hydraulic quick change joints. These quick change joints need to undergo a certain static pressure test before being put into use [1]. The purpose of static pressure test is to test the sealing property of workpiece under certain pressure. The criterion for passing the static pressure test is that the leakage amount of the test medium is less than a few drops after a certain pressure test process [2]. After static pressure test qualified workpiece or product can be applied to production and life. Once these components that fail the pressure test are put into use, most of them will bring serious consequences [3].

The key of static pressure test is to control the pressure. Fluid connectors and hydraulic quick change connectors have strict requirements on the pressure in static pressure test. Failure to meet the test process will cause damage or even more serious loss of the workpiece [4]. In terms of pressure control methods, PID control and fuzzy control are commonly used in pressure test platform at present. Most control algorithms studied today are based on this algorithm. Existing paper studies include parameter self-tuning fuzzy PID control, integral separation PID control, fuzzy PID control, genetic algorithm-based PID control, etc. [5-10]. These studies have obtained the advantages and disadvantages of each control method through comparison and simulation. But these control algorithms from their simulation results can not be fully applicable to the static pressure test system, and in the PLC control system to achieve the difficulty and cost is large. The control structure of PID and fuzzy PID controller is easy to build, and corresponding modules can be used in PLC programming software. Although the dynamic response of the controller is fast, the control effect of these two controllers on some systems may be overshoot, and generally cannot achieve good control effect [11]. For the ultra-high pressure static pressure test system, due to the rapid pressure relief and testing process requirements, overshoot is not allowed in the process of pressurization, and the variable theory domain fuzzy control algorithm has an obvious effect in suppressing overshoot [12]. So this paper studies the variable theory domain fuzzy PID controller used in static pressure test platform pressure control, and static pressure test process simulation test, to verify the variable theory domain fuzzy PID control in static pressure test pressure control effect.

2. PRESSURE CONTROL CIRCUIT FOR STATIC PRESSURE TEST

This static pressure test is mainly to meet the static pressure test of fluid connector, hydraulic quick change joint and other workpiece. Figure 1 is designed for the hydrostatic test of hydraulic test loop, one as the cut-off valve, 2 for high precision filter, 3 for low pressure pneumatic valve, 4 for the pneumatic diaphragm pump, 5, 6 for pneumatic plunger pump, 16 as the cut-off valve, 7, 10, 16, 17 for high-pressure gas control valve, 8, 9 for high pressure one-way valve, 11 for precision pressure gauge, 12 for the pressure gauge switch, 13 is the sensor, 14 is the high pressure filter, 15 is the manual pressure relief valve, the test station is used to place the workpiece under test and auxiliary tooling.

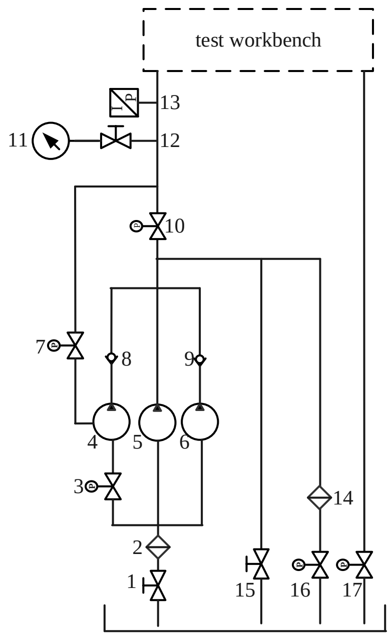

Fig.1 Hydrostatic pressure test hydraulic circuit

The whole static pressure test hydraulic circuit is mainly composed of medium liquid tank, booster pump, filter, each valve, test station, sensor and high pressure pipeline. The working process of the system is as follows: the booster pump works, no. 1 valve is opened, No. 15 valve is closed, no. 4 pump works, and the liquid medium in the medium liquid tank is sent into the station through no. 10 valve, and then comes back to the tank from no. 17 valve. This process is an exhaust process; Disconnect no. 17 valve after a period of exhaust; Then according to the pressure demand to start no. 5 or 6 pump, at this time, no. 16 and 17 valves are closed, through this step can complete the pressure, pressure holding test.

3. PRESSURE CONTROL METHOD

In the static pressure test pressure control system, the on and off of each solenoid valve is controlled by PLC, and the air source pressure of the pneumatic liquid booster pump is controlled by the electric proportional valve, so as to control the output pressure of the pneumatic liquid booster pump. A static pressure test tests that the pressure in the chamber is created by squeezing the liquid. The two ends of the piston rod inside the pneumatic liquid booster pump will reach the stable pressure state when the force is balanced [13]. In this state, the ratio of the pressure at both ends of the piston rod is the inverse ratio of the area of the piston rod. Suppose the air source pressure is P_0, the output pressure of the pneumatic liquid booster pump is P_1, and the pressurization ratio is K_0. The relationship is as follows:

$$P_1 = P_0 \times K_0 \tag{1}$$

The system measures the pressure of the pipeline through the pressure sensor in the pipeline, and the pressure feedback is used as the basis to adjust the opening size of the electric proportional valve, thus forming a closed-loop control. The closed-loop control flow of the system is shown in Figure 2.

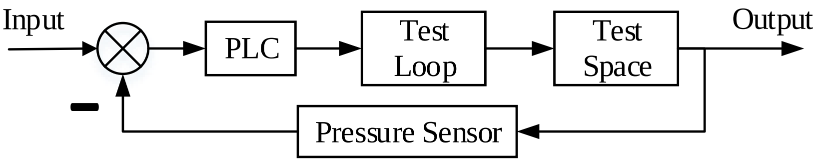

Fig.2 Control flow graph

4. VARIABLE THEORY DOMAIN FUZZY PID CONTROL

4.1 Variable theory domain fuzzy PID control principle

Professor Li Hongxing proposed that the essence of fuzzy controller based on variable theory domain is an adaptive fuzzy controller [14]. The variable theory domain fuzzy PID controller adds the theory domain adjustment mechanism [15] on the basis of the original fuzzy controller, that is, on the premise of invariable fuzzy rules and membership function, the theory domain shrinks or expands with the change of error [16], as shown in FIG. 4. In the process of domain compression, it is equivalent to increasing the number of rules in a certain area. Therefore, the whole algorithm is relatively simple and has better control effect [17].

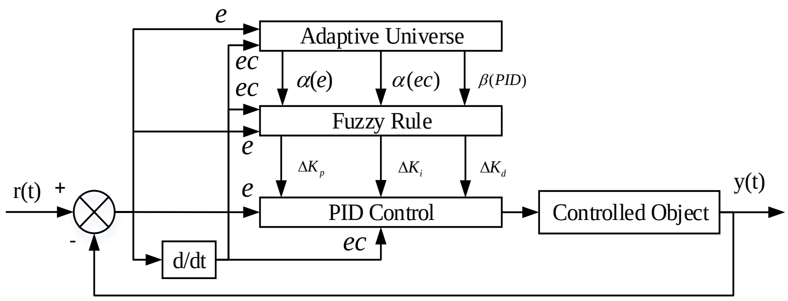

Fig.3 Variable domain fuzzy PID controller configuration diagram

Let P_0,I_0,D_0 be the setting parameters of traditional PID controller. The test pressure error E and the rate of change of the test pressure error EC are the input of the variable theory domain fuzzy controller. After fuzzy reasoning and anti-fuzzization, three parameters ΔK_P, ΔK_I, ΔK_D are obtained. Then these three parameters are summed with the parameters of the original PID controller, and the final PID controller parameters are:

$$\begin{cases} K_P = P_0 + \Delta K_P \\ K_I = I_0 + \Delta K_I \\ K_D = D_0 + \Delta K_D \end{cases} \tag{2}$$

In the above formula, K_P, K_I and K_D are the final control parameters of fuzzy PID controller in variable theory domain.

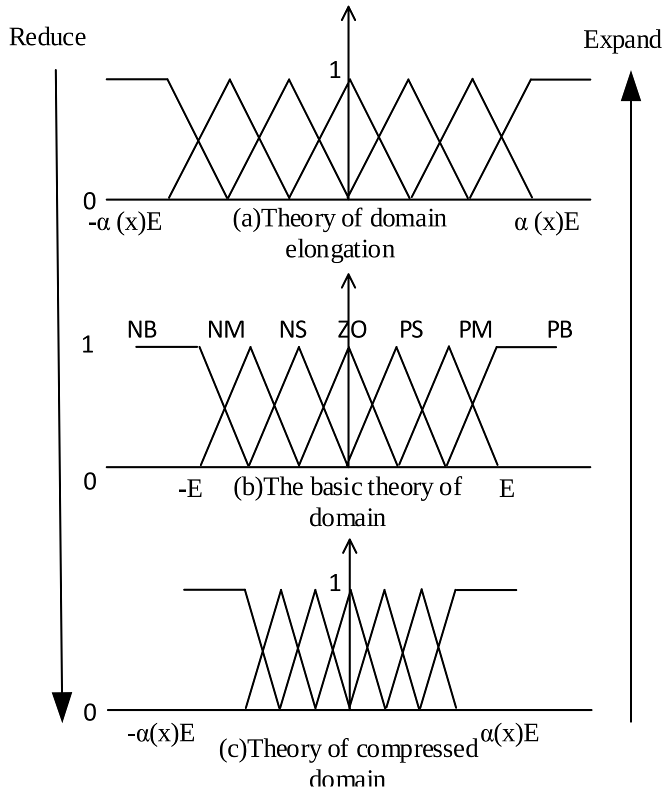

Fig.4 Domain compression and expansion

4.2 Fuzzification

The fuzzy reasoning algorithm is Mamdani algorithm, the fuzzy resolution method is Centroid method and the fuzzy rules are shown in Table 1. The membership function of fuzzy PID controller in variable theory domain is obtained by fuzzification. Different shapes of membership function will have certain influence on the control effect. The fuzzy subset with sharper shape of membership function has higher sensitivity and resolution. Otherwise, the sensitivity and resolution are lower [18].

In order to obtain higher control sensitivity and resolution, the membership function selected here is shown in Figure 5.

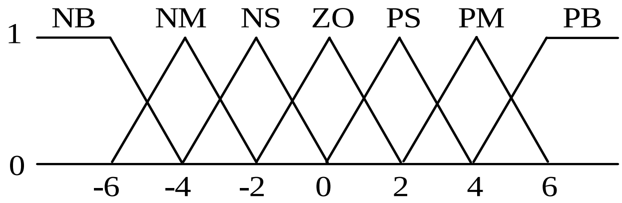

Fig.5 Membership function curve

The theory domain of pressure error E and pressure error change rate EC of fuzzy PID controller in variable theory domain is [-3,3], and fuzzy subsets are defined as 7, {NB, NM, NS, ZO, PS, PM, PB}[19]. The theory domain of the above fuzzy subsets is [-6,6]. According to the actual situation of the pressure test, the actual situation of the test pressure error E is ±50MPa, so the basic theory domain of the design is [-50,50]. After step signal test of the pressure test platform, the change rate of test pressure error (EC) is [-3,3] in the basic theory domain, and the unit is MBPS. The theory domain of test pressure error E and change rate of test pressure error EC are [-2.5,2.5]. The domain of ΔK_P and ΔK_I is [-6,6], and the domain of ΔK_D is [-0.6,0.6]. Thus, the quantization factor K_e=3/50=0.06 of pressure deviation E and the quantization factor K_{ec}=3/2.5=1.2 of change rate of pressure deviation EC can be calculated. Proportional factors K_{p1}=6/6=1, K_{i1}=6/6=1, K_{d1}=0.6/6=0.1.

4.3 Fuzzy Rule

Making fuzzy rules is also an important part of variable theory domain fuzzy PID control. The formulation of fuzzy rules is based on historical experience or practice to adjust the experiment. The fuzzy rules between pressure parameter error E, change rate of pressure parameter error EC and fuzzy controller output ΔK_P, ΔK_I, ΔK_D are shown in Table 1.

4.4 Elastic Factor

The key to variable domain is to select an appropriate expansion factor so as to achieve reasonable expansion of domain. In order to achieve good control effect, an appropriate expansion factor is the prerequisite [20]. Initial field [-E,E] by scaling factor alpha (x) transformation for [-α(x)E, α(x)E], the α(x) is a continuous function of error variable x, α values in the range of (1,1). The definition of the expansion factor α(x) has been explained in literature [21], and the conditions that the expansion factor needs to meet are as follows:

antithetical parallelism: $\forall x \in X, \alpha(x) = \alpha(-x)$;

Protect nature of zero: $\alpha(0) = 0$;

Monotonicity: strictly monotonicity on [0,E];

Coordination: $\forall x \in X, x \leq \alpha(x)E$;

The normality: $\alpha(\pm E) = 1$;

At present, the scaling factor based on the function form is most commonly used, such as:

$$\alpha_1(x) = 1 - \lambda \exp(-kx^2), (0 < \lambda < 1, k > 0) \tag{3}$$

$$\alpha_2(x) = (\frac{|x|}{E})^{\tau}, (0 < \tau < 1) \tag{4}$$

In the existing research results show that the parameters in the expansion factor have a certain influence on the control precision and the domain compression process, the larger the coefficient is, the higher the control precision will be, but the control rate will decrease at the same time; The smaller the coefficient is, the lower the control accuracy is, and the control rate will be improved with better real-time performance [22]. Considering that the pressure test system of aerospace fluid connector requires high control precision of pressure parameters, it requires better dynamic performance in pressure control. In terms of the selection of expansion factor, the simulation comparison of control effect at λ=0.01 and λ=0.95 is compared, as shown in FIG. 6. After simulation comparison, the control effect is better than λ=0.01 when λ=0.95 is selected, and the control effect is better than λ=0.95. Therefore, in this system, the expansion factor is taken as $\alpha(e)=\alpha(ec)=1-0.95e^{-2x^2}$, and on the premise that the number and type of original fuzzy rules remain unchanged, the fuzzy PID controller in variable theory domain is written into the S function module for simulation test.

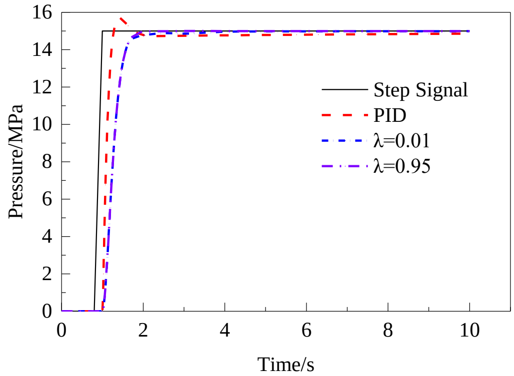

Fig.6 Comparison of expansion factor control effect

Table 1 Fuzzy control rules

$\Delta K_P \backslash \Delta K_I \backslash \Delta K_D$		ec						
		NB	NM	NS	ZO	PS	PM	PB
e	NB	PB\NB\PS	PB\NB\NS	PM\NM\NB	PM\NM\NB	PS\NS\NB	ZO\ZO\NM	ZO\ZO\PS
	NM	PB\NB\PS	PB\NB\NS	PM\NM\NB	PS\NS\NM	PS\NS\NM	ZO\ZO\NS	NS\ZO\ZO
	NS	PM\NB\ZO	PM\NM\NS	PM\NS\NM	PS\NS\NM	ZO\ZO\NS	NS\PS\NS	NS\PS\ZO
	ZO	PM\NM\ZO	PM\NM\NS	PS\NS\NS	ZO\ZO\NS	NS\PS\NS	NM\PM\NS	NM\PM\ZO
	PS	PS\NM\ZO	PS\NS\ZO	ZO\ZO\ZO	NS\PS\ZO	NS\PS\ZO	NM\PM\ZO	NM\PB\ZO
	PM	PS\ZO\PB	ZO\ZO\NS	NS\PS\PS	NM\PS\PS	NM\PM\PS	NM\PB\PS	NB\PB\PB
	PB	ZO\ZO\PB	ZO\ZO\PM	NM\PS\PM	NM\PM\PM	NM\PM\PS	NB\PB\PS	NB\PB\PB

5. PRESSURE CONTROL SIMULATION

The transfer function of the static pressure test circuit is [23]:

$$G(s)=\frac{2}{s^2+3s+1} \tag{5}$$

In order to compare the pressure control effects and verify the control function of fuzzy PID controller in variable theory domain in the static pressure test circuit, the simulation models of PID controller, fuzzy PID controller and fuzzy PID controller in variable theory domain were built, and several static pressure test processes were simulated. The control effects of the three control algorithms were compared under the same target pressure of 15MPa and the same initial PID parameters, i.e. P_0=19.5, I_0 =1.6, D_0=3.75.

In order to ensure the test effect of static pressure test and meet the national standard of static pressure test, the pressure stabilizing effect of the system must be guaranteed.

Therefore, the simulation of pressure leakage in the system is carried out to verify the pressure stabilizing effect of the fuzzy PID controller in the variable theory domain in the face of static pressure test, as shown in Figure 8.

Most static pressure tests are carried out on the workpiece in small batches. In order to conduct an efficient and safe test, it is necessary to keep the pressure of the test chamber at a low level in the early stage of boost, and then boost it after there is no leakage, so as to avoid the loss caused by continuing the high pressure test after leakage under low pressure, as shown in Figure 10.

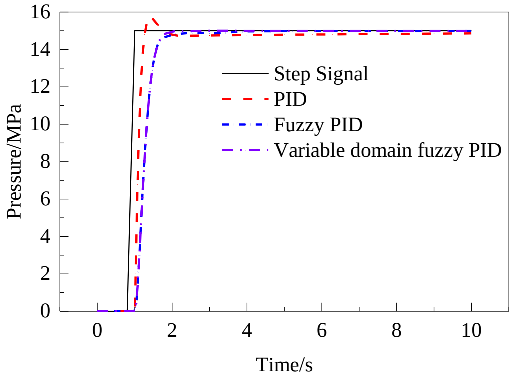

Fig.7 Step signal response

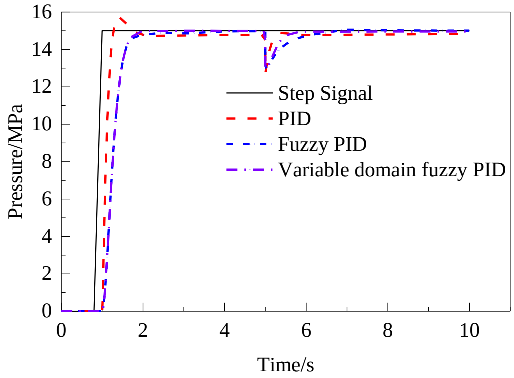

Fig.8 Pressure leakage perturbation simulation

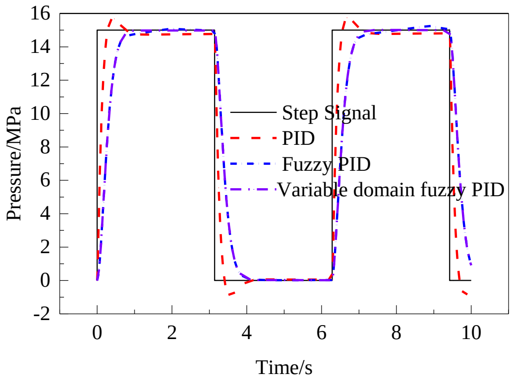

Fig.9 Simulation of square wave pressure variation

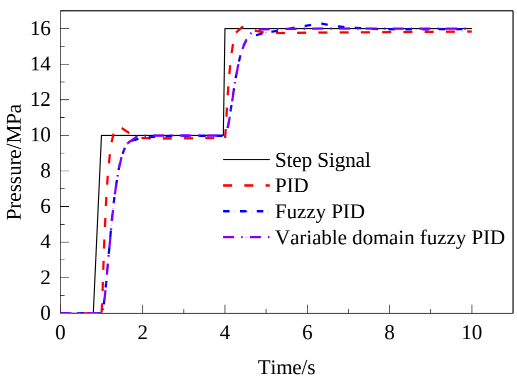

Fig.10 Simulation of target pressure variation

As can be seen from Figure 7, the simulation results of PID controller have overshoot, the overshoot is 4.6%, and the steady-state error is about 1.3%. The pressure control of fuzzy PID controller is more accurate than that of PID controller, but it fluctuates from 2s to 3s and reaches a stable state about 4.5s. It can be seen from FIG. 8 that the pressure of the fuzzy PID control curve rises unsteadily in a few seconds after the pressure is disturbed, and the pressure is higher than the target pressure after reaching the steady state. There is no overshoot in the simulation results of fuzzy PID controller in variable theory domain, and it reaches the preliminary stable state after 2s. After pressure disturbance, it can quickly and smoothly return to the stable state, and the final steady-state error is 0.25%. According to the simulation comparison results in FIG. 9 and 10, overshoot appears in the simulation results of BOTH PID controller and fuzzy PID controller, and the fuzzy PID controller with variable theory domain has the best effect on the target pressure change and anti-interference test in the static pressure test.

6. CONCLUSION

On the basis of static pressure test circuit, combined with variable theory domain fuzzy PID control theory, the designed static pressure test pressure control algorithm was simulated, and the simulation results were compared: The variable theory domain fuzzy PID control method has high control precision in this system. In the face of static pressure test pressure leakage can timely fill the pressure, the pressure rise is stable, no sudden change of pressure, meet the static pressure test strictly control pressure does not exceed the maximum test pressure and other technological processes. The fuzzy PID control algorithm with variable theory domain has better control effect on pressure disturbance in static pressure test, and has certain reference and practical value for practical engineering application.

REFERENCES

[1] Liang X H, Fan Y D. Modeling and simulating for Rising-Pressure System of Isostatic-Pressure Machine based on Simulink[J]. Computer Measurement and Control,2014,22(08):2574-2576.
[2] GB/T 5861-2003, Test method for hydraulic quick-change couplings[S].
[3] Hua Y F, Sheng X M.Research on Multi-channel Water Pressure Testing System Based on AMESim[J]. Computer Knowledge and Technology,2018, (26):202-206.
[4] Zhang D Z. Quality Control of Pressure Test in Pressure Vessel Inspection[J]. Technology and Market,2021, (3):176-177.
[5] Lu G F, Lu D W, Meng B, et al. Parameter self-tuning fuzzy PID controller based on S Function[J]. Journal of North China University of Water Resources and Electric Power Natural Science Edition,2014,(4):68-71.
[6] Shi H M, Shan Z D, Guo Z, et al. Research on Fuzzy PID control of Ink Supply Pressure for Sand Mold Printing[J]. Modern Manufacturing Technology and Equipment,2021,(3):1-5.
[7] Xiong J, Gu H. Research on the Application of Integral Separation PID Control Algorithm in Common Rail Pressure Control[J]. Diesel Engine,2021,(1):15-18.
[8] Chen D G, Feng J Q, Zhou Q. Research on blast furnace top pressure control based on fuzzy PID[J]. Journal of Jiujiang University (Natural Science Edition), 2020, (3):31-34.
[9] Xu S, Lu C H. Adaptive cruise control based on genetic PID algorithm[J]. Automobile Practical Technology,2020(8):45-49.
[10] Gan H Y, Yan Z G. Line Pressure Control System Modeling and Simulation Analysis[J]. Mechanical and Electrical Engineering Technology,2016,(3):90-92.
[11] Hu Y N, Ning K W, Zhao J W. Pulp Consistency Control System Based on Variable Universe Fuzzy PID[J]. China Paper,2019,(1):44-49.
[12] Zhang Y H.Design of variable universe fuzzy PID controller for Water Supply System[D]. University of Science and Technology Liaoning,2012.
[13] Zang Y J. Design and Analysis of a New Type Bidirectional Pneumatic-hydraulic Pressurization System[J]. Hydropneumatics & Sealing,2013,(9):57-58.
[14] Li Hongxing. Adaptive fuzzy controllers based on variable universe[J]. Science in China Series E: Technological Sciences, 1999, (01): 10-20.
[15] Wu H Q. Design of PLC-based variable universe fuzzy PID control positioning servo system of optical fiber connector polishing machine[J]. Application of Automation,2017(9):123-125.
[16] Zhang X, Xu M, Zheng D C, et al. Simulation Analysis of BLDCM Based on Variable Universe Fuzzy PID Control[J]. Micro & Special Motor,2020,(3):54-57.
[17] Tian Y, Shen Z Yi, Liu B G. Study of flex-factor on the variable universe fuzzy controller[J]. Modern Manufacturing Engineering,2005(4):98-100.
[18] Wang J F, Lu Z D. The determine method of membership function in fuzzy control[J]. Henan Science,2000(4):348-351.
[19] Li G Y. Intelligent control and its realization in MATLAB[M]. Electronic Technology Press, 2005.
[20] Li Y, Li K K, Zhang X j. Research and Simulation of Variable Universe Fuzzy PID Control System of Brushless DC Motor[J]. Journal of Shaanxi University of Science and Technology,2017,(5):162-167.
[21] Li H X. The Essence of Fuzzy Control and a Kind of Fine Fuzzy Controller[J]. Control Theory and

Application, 1997(6):868-872.
[22] Yang L. Application research of variable theory domain adaptive fuzzy control in manipulator trajectory tracking[D]. Southwest Petroleum University, 2016.
[23] Zhang D X. Design of Control System of Gas Cylinder Hydraulic Test Equipment Based On Air-driven Liquid Pressurization[D]. Harbin University of Science and Technology, 2017.

About author: Wan Min (1977-), female, ph. D. candidate, professor, research direction: detection technology and automation device. Feng Yixiao (1996-), male, MASTER candidate, research interest in fuzzy control and automation device.