# Design of the Fuzzy Intelligent Controller of Air Compressor

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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. It is difficult for an air compressor system to achieve the on-site production requirements because it is a time-varying, delay and nonlinear complex system. Articles for air compressor control system designed air compressor controller based on fuzzy control provided details of air compressor control strategies. The simulation experiments results showed that air compressor control requirements can be completed very well by controllers.*

**Categories and Subject Descriptors: I.5 [Pattern Recognition]**; Fuzzy set: **I.2.11 [Distributed Artificial Intelligence]**; Intelligent agents

**General Terms:** Intelligent Systems, Fuzzy applications

**Keywords:** Air Compressor, Fuzzy Intelligent Control, Time-Varying System, Pressure Fuzzy Controller, Fuzzy PID Controller

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## 1. Introduction

The air compressor is a key device in the production of air separation. It provides the compressed air of required pressure for the throttle and the expander, it has also become an indispensable key device of the departments of metallurgy, petrochemical industry, national defense, communications, and so on. To ensure the stability of the systematic pressure or flow in the compressor control system is of great significance. With the increasing levels of enterprise automation, equipments become more and more useful to the production. Only if the equipments operate effectively and safely, can the system provide stable power of high quality, thereby improving the quality of products and the efficiency of production.

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.

Large-scale air separation plant often uses the constant pressure control method. To ensure the save and stable operation of the equipments, some auxiliary controls are needed, such as loading/unloading control, anti-surge control, interlock protecting control and on/off control and so on. In the pressure control system of an air compressor, the most important control parameter is the outlet pressure, which can directly affect the performance and productivity of the air compressor.

## 2. Design of fuzzy pressure controller

As there is only one pressure controlled object, the fuzzy pressure controller can be chosen as a single variable. One-dimensional fuzzy controller has only one input value, the deviation $e$, but its dynamic characteristics are poor. On this basis, the two-dimensional fuzzy controller adds a second input value, that is, the change rate of the deviation $e$, which can greatly improve its control performance. Thus the two-dimensional controller is used, and two parameters: the difference of measured pressure and the set value and the changing rate of the difference, are taken as its inlet value, the outlet value is the opening of the inlet guide vane.

After the structure of the fuzzy controller is determined, discrete the input value and do the fuzzy processing to establish the correspondence between the discrete quantity and the fuzzy quantity, so the transform between the precise quantity and the fuzzy quantity can be achieved. In the fuzzy processing, the multiplication of input value and the relative factor should be done. The relative factor denotes the quantization factor and it is represented by $K$ [1].

$$K_e = \frac{p}{x_e} \tag{1}$$

$$K_c = \frac{q}{x_c} \tag{2}$$

In the above formula, $K_e$ stands for the quantization factor with deviation, $K_c$ represents the quantization factor of the error rate, $x_e$ is the deviation value which is the basic input domain, $x_c$ indicates the numerical value in the basic domain of the deviation change rate inputs, $p$ is the maximum parameter of discrete domain corresponding to the deviation input, $q$ is the maximum parameter of discrete domain corresponding to the error rate.

Assume that the basic domain of the controller is $[m, n]$, the domain of the fuzzy set is $[-6, 6]$, then the change from the basic domain to the fuzzy domain is as follows [2]:

$$y = \mathrm{int}\left[\frac{12}{n-m}\left[x - \frac{m+n}{2}\right]\right] \tag{3}$$

Where: $x$ is that the continuous quantity of the basic domain, $y$ is the discrete quantity of the fuzzy set, $int$ indicates the rounding operation.

Controller output chooses the incremental output, that is output multiplied by the scale factor $K_u$ is the acceptable domain of the controlled object.

$$K_u = \frac{y_0}{d} \tag{4}$$

In the formula: $y_0$ is the exact amount of the basic domain of the output, $d$ is the maximum of the discrete domain.

According to the site operator's experience, the basic domain of the deviation $E$ can be identified as $\{-0.5, +0.5\}$, the discrete domain can be identified as $X = \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\}$, and then the quantization factor of deviation is $K_e = 6 / 0.5 = 12$. According to the actual situation, there are seven language variables to be chosen: negative big (NB), negative median (NM), negative small (NS), zero (ZO), and positive small (PS), positive median (PM) and positive big (PB). In the actual project design, the membership function of fuzzy subset in the discrete domain $X$ commonly uses triangular membership function, which has the advantages of fewer amounts of computation and less storage space; it can also meet the requirements of the general control.

The basic domain of the change rate of the deviation $EC$ can be identified as $\{-0.2, +0.2\}$, the discrete domain can be identified as $X = \{-6, -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, 6\}$. then, the quantitative factor of the change rate of the deviation is $K_c = 6 / 0.2 = 30$. According to the actual situation, there are seven language variables to be chosen: negative big (NB), negative median (NM), negative small (NS), zero (ZO), positive small (PS), positive median (PM) and positive big (PB). The incremental output of the fuzzy controller output is adopted, the basic domain of the output $U$ can be identified as $\{0,1\}$, the exact amount $y_0$ generally is 2% of the output, the selection of the rest functions are the same with the deviation and change rate of deviations, thus the output scale factor is.

The control rules of fuzzy controller are described by the IF (a condition is met) THEN (pushed to a conclusion) statement according to the long-term accumulation of operating experience of operator's and the empirical knowledge of experts, to this strategy. The basic control rules are: when the deviation is large, the control amount should be able to eliminate it as soon as possible should be chosen; when the deviation is small, the control amount is to prevent overshoot and keep stable output.

Utilize programming calculation of the fuzzy toolbox in Matlab to get the output value. The area gravity method is adopted as the anti-fuzzy method. The control area of the two-dimensional fuzzy controller is shown in Figure 1.

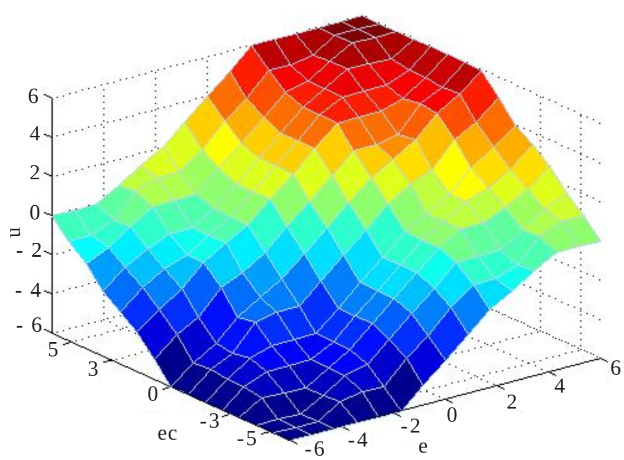


Figure 1. Control area of the pressure fuzzy controller

### 3. Fuzzy PID Controller

Based on the design method of pressure fuzzy controller, the fuzzy PID controller has three control outputs, so its structure using multi-variable fuzzy controller. The controller program structure is shown in Figure 2.

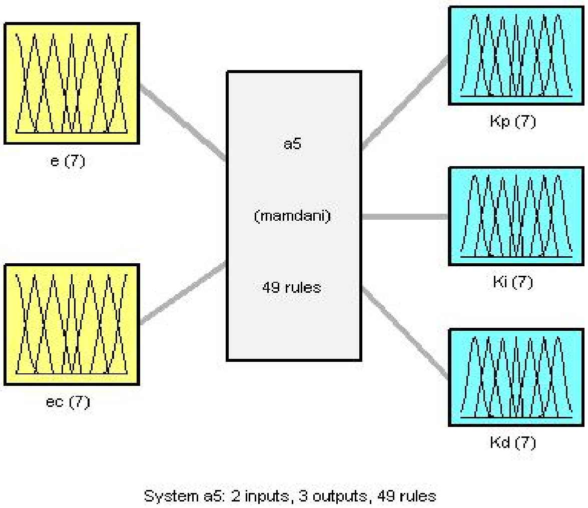


Figure 2. Fuzzy PID control chart

The input variables have two parameters: the deviation $e$ and the rate of deviation change $ec$. the output variable has three parameters: $\Delta K_p$、$\Delta K_i$、$\Delta K_d$. 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 $\Delta K_p$ 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 $\Delta K_i$, its basic domain can be identified as $\{-0.1, +0.1\}$. The coefficients of the differential link $\Delta K_d$, 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:

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

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.

In summary, the combination of long-term accumulation of operational experience and expertise of field operatives, were established $\Delta K_p$, $\Delta K_i$, $\Delta K_d$, fuzzy control rules [3-4] the following 49 statements:

1) If ($e$ is $PB$) and ($ec$ is $PB$) then ($\Delta K_p$ is $NB$) ($\Delta K_i$ is $PB$) ($\Delta K_d$ is $PB$)

2) If ($e$ is $PB$) and ($ec$ is $PM$) then $\Delta K_p$ is $NB$) ($\Delta K_i$ is $PB$) ($\Delta K_d$ is $PS$)

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48) If ($e$ is $NB$) and ($ec$ is $NM$) then ($\Delta K_p$ is $PB$) ($\Delta K_i$ is $NB$) ($\Delta K_d$ is $NS$)

49) If ($e$ is $NB$) and ($ec$ is $NB$) then ($\Delta K_p$ is $PB$) ($\Delta K_i$ is $NB$) ($\Delta K_d$ is $PS$)

## 4. Simulation of the Control System of Air Compressor

Use Simulink blocks in Matlab simulation software to model and simulate the control system of an air compressor. In the case of adding random noise and real-time random noise, the conventional control scheme and the fuzzy self-tuning PID control scheme in the air compressor control are shown separately in Figure 3 and Figure 4.

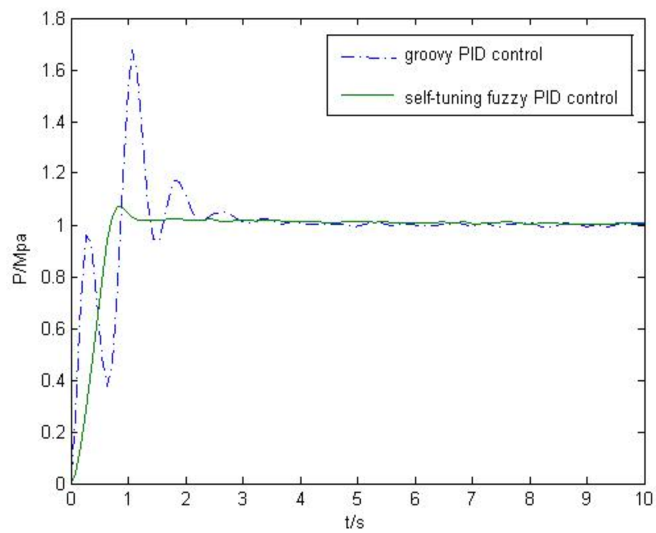


Figure 3. Simulation curve under the random noise

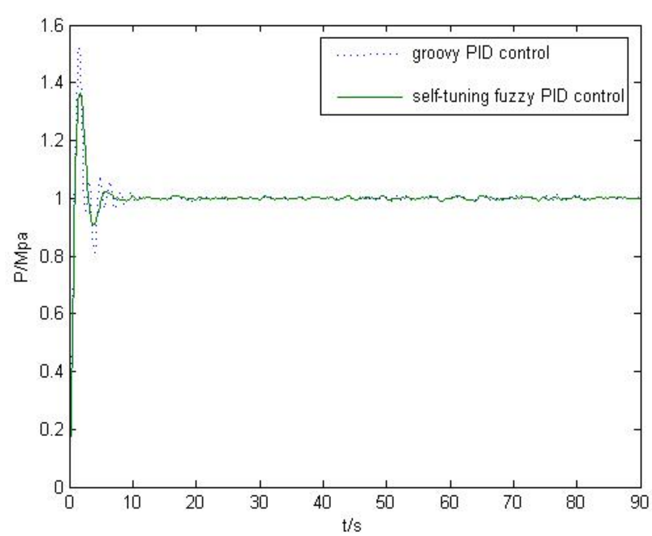


Figure 4. Simulation curve under the real-time random noise

As can be seen from Figure 3 and Figure 4, compared to the conventional control scheme, the designed fuzzy controller in the air compressor control has a better control result: the time to reach stable control is less, the overshoot is smaller, the anti-disturbance capacity is stronger, the controlled system can also reach a steady state more easily. Its control performance is obviously superior to the conventional control scheme.

## 5. Conclusion

Based on the impact of the key control parameters on air compressor, using the fuzzy control theory, for the traditional control method and controller easily lead to the air compressor outlet pressure fluctuations of greater volatility causing problems, air compressor pressure fuzzy control model is established. Did the pressure fuzzy controller design and the fuzzy PID controller design of air compressor control system. The simulation experiment results verified the effectiveness of the designed control system, and it has strong robustness and adaptability.

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Dr.Gongfa Li received the Ph.D. degree in mechanical design and theory from Wuhan University of Science and Technology in China. Currently, he is an associate professor at Wuhan University of Science and Technology, China. His major research interests include modeling and optimal control of complex industrial process. He is invited as a reviewer by the editors of some international journals, such as Environmental Engineering and Management Journal, International Journal of Engineering and Technology, International Journal of Physical Sciences, International Journal of Water Resources and Environmental Engineering, etc. He has published nearly ten papers in related journals.

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