Research on Precise Control of a Cylinder Delay Oscillation System Based on Response Surface and Genetic Algorithm

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Abstract. A cylinder time-delay oscillation system can be constructed by using air bag and throttle valve. The air bag and throttle valve are used to realize the time-delay transmission of pressure in the feedback circuit, and the feedback pressure is used to promote the reversing of two position five-way valve, so as to realize the reciprocating action of the cylinder. The experimental design is carried out based on the simulation analysis, and the response surface is constructed based on the experimental data to clarify the relationship between the cylinder dwell time and the main component parameters. Based on response surface, genetic algorithm is used to search for the best control parameters to realize the accurate control of cylinder dwell time.

1. Introduction
Pneumatic transmission system is widely used in various actuators of industrial automation. It has the advantages of fast, environmental protection, low cost and easy control. Among them, the cylinder control system to realize linear reciprocating action is the most common module. Through the combination of multiple such modules, more complex action tracks can be realized.

There are many ways to realize the linear reciprocating motion of the cylinder, such as using a travel switch or proximity sensor, combined with a certain controller or control valve. This paper mainly discusses a control system using air bag and throttle valve to realize linear reciprocating motion, as shown in Figure 1. The main advantages of the system are that there is no need to add controllers and sensors, the cost is relatively low, the collision of travel switch is avoided, the system operation noise is less, and the pause time of cylinder can be adjusted according to needs.

![Figure 1. Principle of cylinder delay oscillation system.](image)
The system mainly uses the air bag and throttle valve to realize the time-delay transmission of pressure in the feedback loop, and uses the feedback pressure to push the two position five-way valve to reverse, so as to realize the reciprocating action of the cylinder. The main problem of the system is that it is difficult to accurately calculate and control the pause time of the cylinder. Based on simulation analysis technology, this paper constructs response surface through experimental design, and then uses genetic algorithm to obtain accurate control parameters.

2. Construction of simulation model of cylinder delay oscillation system
Based on the pneumatic component library, pneumatic component design library and mechanical component library provided by AMESim software, the simulation analysis model can be constructed, as shown in Figure 2.

The displacement line diagram of cylinder piston rod is obtained through simulation, as shown in Figure 3. At the beginning of the first cycle, the system is in an unstable state. It enters the steady state from the second reciprocating motion, and the pause time remains the same every time.
3. Constructing response surface based on experimental design

3.1. Experimental design principle
Central composite design is the most commonly used second-order response surface experimental design method. This method is a mainstream second-order response surface experimental design method. It combines the traditional interpolation node distribution with full factor or partial factor design, and can provide more information with as few experimental times as possible.

Response surface design is a method to effectively establish the relationship between test indexes and continuous variables through a small amount of test data. Its basic idea is to approximately construct a polynomial model with explicit expression in a small area to express a complex unknown function relationship. Based on experimental design and mathematical statistics, this method not only considers the experimental random error, but also has simple calculation. It is an effective means to solve the problem.

3.2. Design variable selection and simulation experiment
According to experience, the volume of the airbag affects the inflation time, the diameter of the orifice affects the gas flow, and the load mass affects the inertial load. Therefore, the airbag volume, orifice diameter and load mass are selected as the factor variables of the experiment, which are recorded as \( X_1 \), \( X_2 \) and \( X_3 \) in sequence. The simulation analysis is carried out according to the central composite design, and the experimental design table is obtained, as shown in Table 1.

| NO. | \( X_1 \)/L | \( X_2 \)/mm² | \( X_3 \)/kg | \( Y \)/t |
|-----|-------------|---------------|--------------|----------|
| 1   | 20          | 0.2           | 40           | 1.38900023e+00 |
| 2   | 40          | 0.2           | 40           | 1.57350021e+00 |
| 4   | 40          | 0.4           | 40           | 1.31362523e+00 |
| 3   | 20          | 0.4           | 40           | 9.9862571e-01 |
| 6   | 40          | 0.2           | 80           | 1.5791251e+00 |
| 5   | 20          | 0.2           | 80           | 1.38562523e+00 |
| 7   | 20          | 0.4           | 80           | 9.9862571e-01 |
| 8   | 40          | 0.4           | 80           | 1.31137523e+00 |
| 9   | 30          | 0.3           | 60           | 1.33725023e+00 |
| 10  | 10          | 0.3           | 60           | 9.18750281e+00 |
| 12  | 30          | 0.1           | 60           | 1.69950020e+00 |
| 11  | 50          | 0.3           | 60           | 1.52176520e+00 |
| 14  | 30          | 0.3           | 20           | 1.3387524e+00 |
| 13  | 30          | 0.5           | 60           | 1.04812526e+00 |
| 15  | 30          | 0.3           | 100          | 1.32712523e+00 |

3.3. Construction of response surface
The response surface can be constructed according to the experimental design table, such as formula (1). The expression can be used to replace the simulation mode, and the optimization design can be carried out directly, which can greatly reduce the amount of calculation and improve the analysis efficiency.

\[
Y = \begin{bmatrix}
1 & \beta_{10} & \beta_{11} & \beta_{12} & \beta_{13} \\
X_1 & X_1^2 & X_1 X_2 & X_1 X_3 & X_1^3 \\
X_2 & X_2^2 & X_2 X_1 & X_2 X_3 & X_2^3 \\
X_3 & X_3^2 & X_3 X_1 & X_3 X_2 & X_3^3
\end{bmatrix} \begin{bmatrix}
\beta_{11} \\
\beta_{11} \\
\beta_{11} \\
\beta_{11}
\end{bmatrix}
\]

(1)
3.4. Experimental data analysis
Through the experimental design, the graph can be drawn to intuitively analyze the relationship between variables. Firstly, the response surface of pause time to airbag volume and orifice diameter is analyzed, as shown in Figure 4. There is a significant positive correlation between cylinder dwell time and airbag volume, and this correlation is stronger when the throttling area is about large. There is a significant negative correlation between cylinder dwell time and throttle area, and this negative correlation will be stronger when the airbag volume is small.

![Figure 4](image1.png)

Figure 4. Y response to $X_1$ and $X_2$.

Next, the response surface of cylinder dwell time to load mass and airbag volume is analyzed, as shown in Figure 5. There is a significant positive correlation between cylinder dwell time and airbag volume. In contrast, the effect of phase load mass on time is not obvious.

![Figure 5](image2.png)

Figure 5. Y response to $X_1$ and $X_3$.

Finally, the response surface of cylinder dwell time to load mass and throttle area is analyzed, as shown in Figure 6. There is a significant negative correlation between cylinder dwell time and throttle area. In contrast, the effect of phase load mass on time is not obvious. Through the above analysis, it can be seen that the key to control the accurate pause time of the cylinder lies in the two parameters of airbag volume and throttling area.

![Figure 6](image3.png)
4. Obtaining precise control parameters based on genetic algorithm

Based on the engineering application case, the following optimization design requirements can be determined. The load of pneumatic system is usually determined according to the working requirements, which is not used as the design variable, and may be taken as 30kg. Airbag components are not easy to replace. They are usually controlled by adjusting throttle valve. Therefore, the airbag volume is set to 10L, and the throttling area is taken as the design variable. According to the working requirements, the pause time of the cylinder is required to be 1s, which is the optimization target.

Expression (1) is optimized by genetic algorithm. After more than 300 iterations, the optimal value of throttling area is 2.86304107744594, as shown in Figure 7.

Take two significant digits after the decimal point of the optimization result, i.e. 2.86, and replace it into the simulation model for analysis. The cylinder displacement line diagram is shown in Figure 8. The cylinder pause time is 1.025s, and the relative error is only 2.5%.
5. Conclusion
The simulation analysis of a cylinder delay oscillation system is carried out, and the response surface is constructed based on the experimental data to clarify the relationship between the cylinder pause time and the main component parameters. Based on response surface, genetic algorithm is used to search for the best control parameters to realize the accurate control of cylinder dwell time.

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