The Design and Simulation of Full Pneumatic Suspension Lifting System

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Abstract. Suspended pneumatic lifting system can improve production efficiency and working conditions as of such great significance. Aiming at disadvantages of domestic research, a necessary development on a kind of pneumatic lifting system widely used in various industrial production occasions is vital. The dynamic mathematical model of pneumatic lifting system was built based on Matlab/Simulink software. In terms of fuzzy PID controller designs for the system, parameters PID controls are set with the default value of fuzzy PID controller, and the simulation results show that: the system settling time is in the range of 0.5~0.8s, steady-state error is in the range of 0~3%.

1. Introduction

The pneumatic lifting system has the characteristics of simple structure, low price, high efficiency, energy saving and no pollution. It is not only widely used in home appliance manufacturing, automotive assembly, weapons production and other industrial fields, but also improves production efficiency and working conditions as of such great significance.

The pneumatic lifting system developed by kony crane in Finland can keep the load in a "free-floating" state. D-BP wire rope balancer developed by the American DMG company can achieve double - weight balance. By using the control strategy based on the observer and the fuzzy control algorithm, a kind of constant pressure control system is developed by Dr. Lu bo, Zhejiang university of China. Shanghai Yongqian company has designed a upper and lower action balance control method of the pneumatic balance crane by using the rotating control handle near the load balance [1].

Aim at disadvantages of domestic pneumatic lifting system, such as, small load, slow response, large damping, a pneumatic lifting system is designed with electric control and pneumatic drive. Through the design of the overall scheme of the system, the labor intensity of the workers would be reduced, the working environment would be improved, and the production efficiency would be improved [2].

2. The Design for overall control program of full pneumatic suspension lifting system

The cylinder piston of pneumatic lifting device has a force balance every moment and everywhere in the whole lifting process. This situation is expressed as below:

\[(p - p_a)A_c = F_z + F_f\]  \hspace{1cm} (1)

\[F_z = \frac{2\pi(Mg + F)R}{\eta L}\]  \hspace{1cm} (2)
where $p$ represents pressure of the cylinder, $M$ represents mass of the load, $F_f$ represents cylinder frictional force, $A_e$ represents the effective action area of cylinder piston, $P_a$ represents atmospheric pressure, $g$ represents acceleration of gravity.

Because of the serious nonlinear and hysteresis existed in the inflating and bleeding process of cylinder, there are errors between the pressure signal output by cylinder and the voltage signal input into the electric proportional valve. To improve the system dynamic response process and reduce the static error, a corresponding controller must be designed for the proportional valve-cylinder system. The hardware structure relationship of the system is shown in Fig.1.

![Figure 1. Pneumatic lifting system principle diagram of the overall control scheme](image1)

3. The simulation of full pneumatic suspension lifting system

3.1. Flow equation modeling

Based on gas continuity equation and ideal gas state equation, the value of gas mass flow can be obtained as follows:

$$
\frac{dm}{dt} = \begin{cases} 
\frac{2}{\kappa + 1} \frac{\kappa + 1}{\kappa - 1} \sqrt{\frac{\kappa}{R T_s}} P_s \omega & \left( \frac{P_s}{P} \leq b_\omega \right) \omega = 1 \\
\frac{2}{\kappa + 1} \frac{\kappa + 1}{\kappa - 1} \sqrt{\frac{\kappa}{R T_s}} P_s \omega & \left( b_\omega \leq \frac{P}{P_s} \leq 1 \right) \omega = \sqrt{\frac{P / P_s - b_\omega}{1 - b_\omega}} \end{cases}
$$

(3)

where $\kappa$ represents adiabatic exponent, $R$ represents gas constant, $P_s$ represents bleed pressure, $T_s$ represents bleed temperature, $S_i$ represents effective flow area.

The corresponding simulation model of flow equation when inflating can be concluded by Eq. 3, just like Fig.2. The encapsulation is shown in Fig.3.

![Figure 2. The flow calculation simulation model of air inflation](image2)

![Figure 3 Flow calculation encapsulation model](image3)

3.2. Pressure equation modeling

Eq. 4 [3] can be got according to the first law of thermodynamics, and the kinetic energy and potential energy of the gas are ignored.

$$
\frac{dP}{dt} = \left( \frac{dm}{dt} \frac{P}{R T_s} \frac{dV}{dt} \right) \frac{\kappa R T_s}{V}
$$

(4)
When proportional valve is closing, \( \frac{dm}{dt} = 0 \). The value of the change of pressure can be obtained as follows:

\[
\frac{dP}{dt} = \left( 0 - P \frac{dV}{dt} \right) \frac{kR}{V} = \frac{RT}{V} \frac{dV}{dt}
\]

(5)

According to Eq. 4 and Eq. 5, when proportional valve is closing or opening, the simulation models of cylinder pressure variation calculation is just like Fig. 4 and Fig. 5 showed. The encapsulation is shown in Fig. 6 and Fig. 7.

**Figure 4.** The simulation models when proportional valve is opening

**Figure 5.** The simulation models when proportional valve is closing

**Figure 6.** The encapsulation when proportional valve is opening

**Figure 7.** The encapsulation when proportional valve is closing
3.3. Dynamic equation modeling

Based on the dynamic equation model of cylinder, movement speed and displacement of the load of the cylinder can be obtained as follows [4]:

\[
(P - P_a) A_e = M \frac{d^2x}{dt^2} + C \frac{dx}{dt} + Mg
\]  

(6)

Based on Eq. 6, there is calculate model of movement speed and displacement of the load of the cylinder, just like Fig.8.

Figure 8. Model of movement speed and displacement of the load of the cylinder

3.4. Total Model of pneumatic lifting system

Total model of pneumatic lifting system is a combination [5], just like Fig.9. Fig.10 is the encapsulation of Fig.9.

Figure 9. Simulation model of valve-control cylinder

Figure 10. Encapsulation model of valve-control cylinder
The structure of PID control system is established based on the model of valve control cylinder. Just like Fig.11.

Figure 11. Simulation model of PID control system

4. Design of fuzzy PID controller
The control system of this article took STEP7-Micro/WIN V4.0 of Siemens S7-200 series as slave system to programme PLC, and downloaded the final program to RAM in PLC[6].

4.1. Build simulation block diagram
This article established PID controller, fuzzy controller and fuzzy PID controller in Matlab/Simulink, just like Fig.12, 13, 14, 15, 16 and 17 showed. The fuzzy PID controller block diagram can be got by connected the encapsulations in Fig.17 and Fig.18, just like Fig.19 showed. The simulation model of fuzzy self-tuning PID control system can be got by combining the encapsulations of Fig.16 and Fig.11, just like Fig.17 showed.

Figure 12. PID controller block diagram
Figure 13. Fuzzy controller block diagram
Figure 14. Encapsulation of PID controller
Figure 15. Encapsulation of fuzzy controller
Figure 16. Fuzzy PID controller block diagram

Figure 17. The simulation model of fuzzy self-tuning PID control system

4.2. Simulation and result analysis

System parameters and system parameters can be got from Table 3 and Table 4, the presetting parameters of fuzzy PID control system is $k_p^* = 1.43$, $k_i^* = 0.06$, $k_d^* = 0.04$ [7].

Simulation result is just like Fig.18, Fig.19 showed. From the result, we can get that setting time of fuzzy PID control system is in the range of 0.5–0.8s. The error rate is 0–0.3% in response curve of every load, it’s hard to eliminate by adjusting the controller. The possible reason is that the value of damping factor is little than the real [9].

Figure 18. Response curve with load of 25kg
For further observation, enlarge the bottom of the simulation curve, just like Fig.20. From the picture, we can get that system response curve has a delay at the beginning. The possible reasons are that the initial pressure of the cylinder is set as atmospheric pressure [10]. When the gas passes through the trachea from the gas source to the trachea, the pressure of the cylinder is almost constant. Therefore, the response curve has a delay, and the delay time is close to 0.15s.

5. Conclusion
The mathematical model of valve control cylinder system was established based on flow equation, pressure equation and dynamic equation of cylinder firstly. Based on matlab/simulink platform, fuzzy self-tuning PID controller is simulated and analyzed. From the simulation result, we can get that through the adjustment of fuzzy self-tuning PID controller, system time is within 0.8 s and steady state error rate is within 3%.

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