A Study on Energy Saving Algorithm of Pneumatic Regulator with Modified PWM Driven Method

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Abstract: The development of an accurate and energy saving pneumatic regulator that may be applied to a variety of practical pressure control applications is described in this paper. A novel modified pulse width modulation(MPWM) valve pulsing algorithm allows the pneumatic regulator to become energy saving system. A comparison between the system response of conventional PWM algorithm and that of the modified PWM(MPWM) algorithm shows that the control performance is almost the same, but energy saving is greatly improved by adopting this new MPWM algorithm. The effectiveness of the proposed control algorithm is demonstrated through experiments with various reference trajectories.

Keywords: pneumatic, on/off solenoid valve, pressure control, PID control, PWM

1. Introduction

Pneumatic system doesn't need to use extra power equipment because the compressed air is used in most industrial environment and it has the merit of low pollution and low cost. Most of conventional pressure control applications among the pneumatic systems are not appropriate for accurate control because they are operated by manual. In other words, manual operation is difficult to control the system pressure proportionally because only on/off operation is possible when we use this system. T. N. Huu controlled the displacement using a pneumatic servo valve[1,2] and S. G. Lee effectively controlled an on/off valve using PI controller and PWM driving method[3]. H. S. Cho and C. W. Lee proposed the deadband and pulseband of modified on/off controller with PD control and studied the pulse modulated value and pulse band ratio.

This paper describes a novel modified pulse width modulation valve pulsing algorithm for improving the accuracy of pressure control and the energy saving of pneumatic regulator.

2. Proposed Modified PWM Algorithm

2.1 System Structure

Pneumatic regulator can control system pressure proportionally and consists of controller, air supply solenoid valve and exhaust solenoid valve, exhaust and supply valve, pressure sensor and diaphram. Fig. 1 shows system configuration.

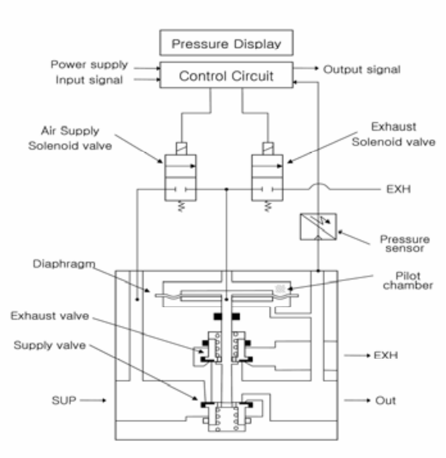

Fig. 1 System configuration

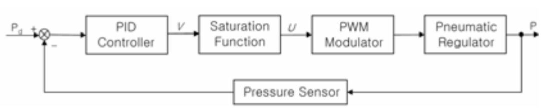

Fig. 2 The structure of the basic control algorithm

Fig. 2 shows the structure of the basic controller composed of PID controller, PWM modulator, air supply/exhaust solenoid valve. PID controller for pressure control of pneumatic regulator is represented by the following equation.

$$V = K_p \cdot (P_d - P) - K_d \cdot P_v + K_i \cdot \int (P_d - P)dt \qquad (1)$$

V : Control Input $\quad$ P_d : Desired Pressure
P : System Pressure $\quad$ P_v : Derivate of Pressure
K_p : Proportional Gain $\quad$ K_i : Integral Gain
K_d : Derivative Gain $\quad$ t : Continuous Time

The control input value '*V*' is calculated by the PID controller and it is converted to PWM output by saturation function. The pressure of pneumatic regulator is controlled by driving air supply or exhaust solenoid valve according to the PWM output

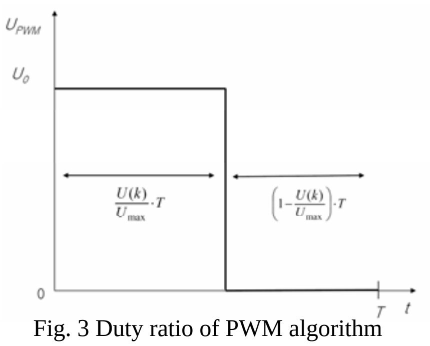

Fig. 3 Duty ratio of PWM algorithm

Fig. 3 shows the change of pulse width time with respect to the duty ratio. Here U_{PWM}, U_0, $U(k)$, U_{max}, k and T denote PWM output voltage, applied voltage for opening solenoid valve, output of saturation function, maximum value of saturation function, discrete time and a cycle of PWM, respectively. Here the opening time of solenoid valve becomes T, if $U(k)$ is larger than U_{max}.

2.2 Conventional PWM Algorithm

Conventional on/off driven method can't control the pressure of pneumatic regulator proportionally but as seen from Fig. 4, the pressure of pneumatic regulator is proportionally controlled by adjusting the opening time of solenoid valve. The opening time of solenoid valve is adjusted by the output of saturation function. Saturation function limits the PID control value between 0 and 1.

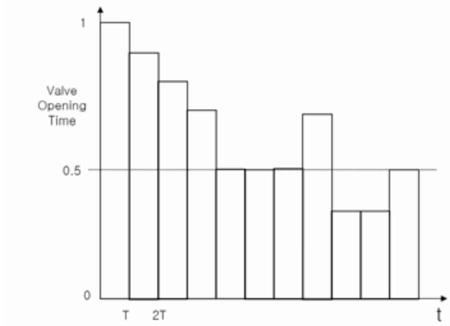

Fig. 4 Valve opening time by conventional PWM

Hyperbolic tangent sigmoid function is used as saturation function and is represented by the following equation.

$$U(k) = \frac{1}{1+e^{-V(k)}} \qquad (2)$$

Here $V(k)$ is discrete value of PID control output. In this case, U_{max} becomes 1 and the opening time of the solenoid valve for a cycle is determined by the multiplication of u(k) and cycle time T. The algorithm for calculating pulse width time of solenoid valve is represented by the following expression.

$$U_{PWM} = \begin{cases} U_0 & 0 \le t \le t_p(kT) \\ 0 & t_p(kT) < t \le T \end{cases} \qquad (3)$$

$$t_p(kT) = \frac{U(k)}{U_{\max}} \cdot T$$

t_p : Opening time of the solenoid valve for a cycle

For instance, the opening time of air supply solenoid valve is *0.6T* if the output of saturation function is *0.6* and the opening time of exhaust solenoid valve is *(1-0.6)T = 0.4T*. However, a lot of energy is wasted by above-mentioned algorithm because air apply and exhaust solenoid valve are alternately made on/off operation for a cycle even if system pressure reaches the desired pressure.

2.3 The modified PWM algorithm for energy saving

A conventional PWM algorithm has the advantage of rapidly reaching the desired pressure but energy consumption is big. Therefore, a new algorithm for energy saving and improvement of the control performance is newly proposed as follows. Fig. 5 shows the valve opening time by the proposed PWM algorithm.

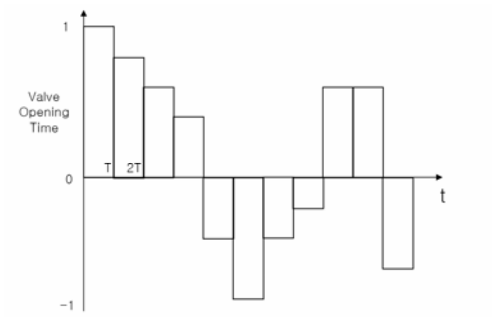

Fig. 5 Valve opening time by proposed PWM

Here, modified hyperbolic tangent sigmoid function is used as saturation function, which is represented as the following equation.

$$U(k) = \frac{2}{1+e^{-V(k)}} - 1 \qquad (4)$$

The output of saturation function has the range from '-1' to '1'. If the sign of saturation function output is '+', just air supply solenoid valve is operated and exhaust solenoid valve is operated if the sign of saturation function output is '-'. Equation (5) shows the algorithm calculating the opening time of solenoid valve.

$$U_{PWM\_IN}(t) = \begin{cases} U_0 & (k-1)T \le t \le (k-1)T + t_{p1}(k) \\ 0 & (k-1)T + t_{p1}(k) \le t < kT \end{cases}$$

$$t_{p1}(k) = \begin{cases} \dfrac{U(k)}{U_{\max}} \cdot T & U(k) > 0 \\ 0 & U(k) < 0 \end{cases} \quad (5)$$

$$U_{PWM\_EX}(t) = \begin{cases} U_0 & (k-1)T \le t \le (k-1)T + t_{p2}(k) \\ 0 & (k-1)T + t_{p2}(k) \le t < kT \end{cases}$$

$$t_{p2}(k) = \begin{cases} 0 & U(k) > 0 \\ \dfrac{|U(k)|}{U_{\max}} \cdot T & U(k) < 0 \end{cases}$$

$U_{\text{PWM\_IN}}$: PWM Output Voltage of Air Supply Solenoid Valve

$U_{\text{PWM\_EX}}$: PWM Output Voltage of Exhaust Solenoid Valve

For instance, the opening time of air supply solenoid valve is *0.6T* if the output of saturation function is *0.6* and exhaust solenoid valve are always closed. Conversely, the opening time of exhaust solenoid valve is *0.6T* if the output of saturation function is *-0.6* and air supply solenoid valve are always opened.

3. Experiments

In this experiment, a conventional PWM and the proposed PWM driven method are applied for the pressure control of pneumatic regulator. The performance of pressure control is compared and examined. Fig. 6 shows the sine response and the number of on/off valve operation, which can be seen in PID value, by conventional PWM driven method. The maximum tracking error is 0.061MPa. Fig. 7 shows the sine response and the number of on/off valve operation, which can be seen in PID value, by the proposed PWM driven method. The maximum tracking error is 0.056MPa. The results of experiments show that the tracking performance is almost the same.

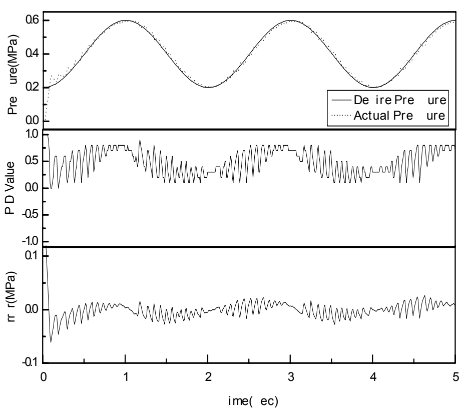

Fig. 6 Experimental results of sine response by conventional PWM

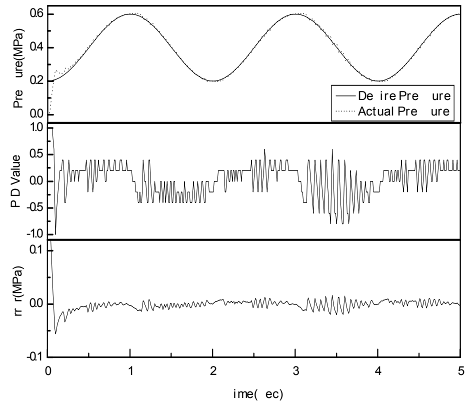

Fig. 7 Experimental results of sine response by proposed PWM

Fig. 8 shows the increasing step response and the number of on/off valve operation, which can be seen in PID value, by conventional PWM driven method. The maximum tracking error is 0.198MPa. Fig. 9 shows the increasing step response and the number of on/off valve operation, which can be seen in PID value, by the proposed PWM driven method. The maximum tracking error is 0.198MPa.

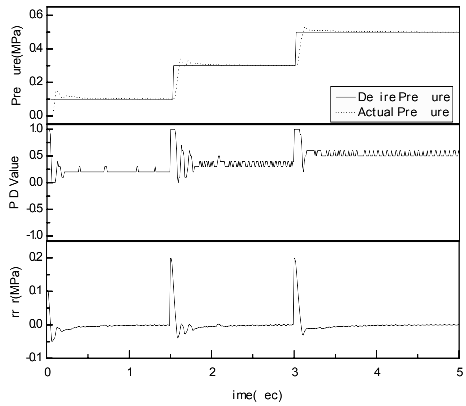

Fig. 8 Experimental results of increasing step response by conventional PWM

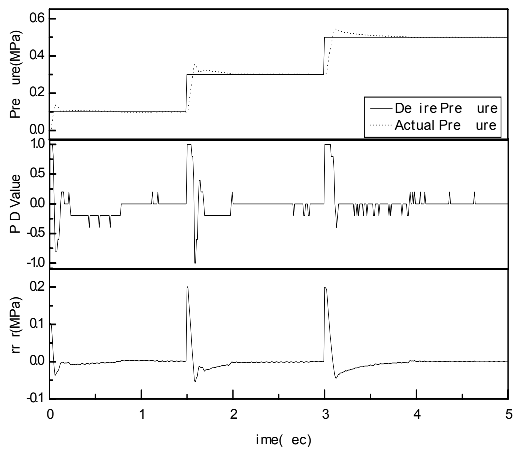

Fig. 9 Experimental results of increasing step response by proposed PWM

Fig. 10 shows the comparison of valve opening time between conventional PWM driven method and proposed PWM driven method. The opening time of air supply solenoid valve is represented by the upper part in the figure and the opening time of exhaust solenoid valve is represented by the lower part in the figure. The opening time of solenoid valve is proportional to the width of the rectangle with oblique lines. In the conventional PWM algorithm, both of the air supply and exhaust solenoid valve are operated 5times but the air supply and exhaust solenoid valve are operated 3times and 1time respectively by using the proposed PWM algorithm. That is, the consumption of electric energy can be reduced significantly with the proposed PWM algorithm.

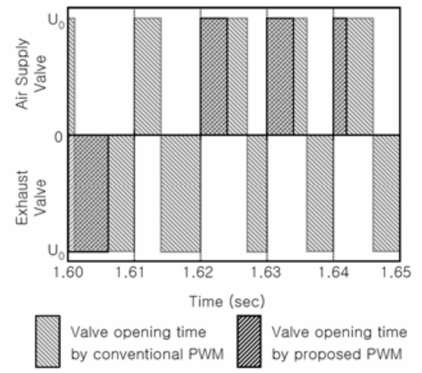

Fig. 10 Comparison of valve opening time

4. Conclusion

A on/off driven type of conventional pneumatic system can not control the pressure of the pneumatic valve proportionally. And also, a conventional PWM driven method of pressure control has good tracking ability but it has a big consumption of electric energy.

In this paper, modified PWM algorithm is proposed for the control of pressure of pneumatic regulator. The proposed PWM algorithm has almost the same tracking performance with the conventional algorithm. However, the proposed PWM algorithm has good settling ability and energy saving. The proposed PWM algorithm operates the air supply solenoid valve when the sign of PID controller output is positive and it operates the exhaust solenoid valve when sign of PID controller output is negative. That is, the consumption of electric energy can be reduced significantly with the proposed PWM algorithm.

Acknowledgement

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