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Closed-Loop PID Control with PWM technique of a Rotary Pneumatic Actuator Using ON-OFF Solenoid Valve

Natdanai Tantawiroon[1,*] and Pornporm Boonporm[2]

[1] Department of Mechanical Engineering, Faculty of Engineering, Kasertsart University
Kamphangsaen campus, Nakhon Phathom, Thailand 73140
[2] School of Mechanical Engineering, Institute of Engineering, Suranaree University of Technology,
Nakhon Ratchasima, Thailand 30000

*Corresponding Author: Tel. 034 355310, Fax. 034 355310
E-mail: fengndn@ku.ac.th

Abstract

This paper presents the Proportional plus Integral plus Derivative feedback control (PID) of on-off solenoid valve by applying the pulse width modulate (PWM) technique for controlling the position of a rotary pneumatic motor mainly use in low-load moderate-precision robotic arm. Test bed consists of rotary pneumatic actuator coupled with potentiometer for angle measurement. PWM signal was generated from DAQ card using LabView control program executed on desktop PC with LabView real-time operating system. From step input test signal rise time of 0.2 s settling time is 0.3 s overshoot of 5.5% was observed and maximum steady-state error of 3% was achieve. The Novel in this experiment is above literature reviews that no test has done on rotary actuator. Rotary pneumatic actuator use in this experiment is of rack and pinion type which consists of two cylinders with rack assemble move in opposing direction to drive the pinion. This configuration poses a problem due to parametric variation of two cylinders. Gains have to be adjusted individually for each cylinder. In conclusion PID-PWM technique can successfully control position of rotary pneumatic actuator with respectable time response and steady-state error.

Keyword: Pneumatic actuator, Rotary actuator, On-off solenoid valve, PWM, PID

1. Introduction

The Pneumatic control system plays nowadays always important roles in the industrial especially in automation of production machinery and in field of automatic controller for the reason of e.g. its cleanliness in the working environment cheaper price and easiness in transfer of power. The pneumatic power is converted to straight line reciprocating and rotary motion by pneumatic cylinder and pneumatic motor. The pneumatic position servo systems are used in numerous applications because of their ability to position loads with high dynamic response

Because of the expensive servo valve, we look for alternative choice for the reasonable price on-off solenoid valve that can work as good as the servo one by applying the control technique to develop a fast accurate pneumatic actuator system

There have been many researches in last decades about position control of a pneumatic cylinder, which are driven by servo valves or on-off solenoid valves. For instance Ref [1] show the development of a fast, accurate, and inexpensive position-controlled pneumatic actuator that may be applied to a variety of practical positioning applications is described. A novel pulse width modulation (PWM) valve pulsing algorithm allows on/off solenoid valves to be used in place of costly servo valves. The main trend seems to be towards servo-pneumatics which has high performance but high costs. In Ref [2] conducted to develop a kinematics control-based pneumatic system. Both position and velocity of the pneumatic piston are controlled and a hybrid of fuzzy and PID is proposed. The modified PMW is proposed in [3] also apply to solenoid valve. A comparison between the system response of the standard and modified PWM technique shows that control performance was significantly increased. A state-feedback controller with position, velocity and acceleration feedback was successfully implemented as a continuous controller. A switching algorithm for control parameters using a learning vector quantization neural network (LVQNN) has newly proposed, which classifies the external load of the pneumatic actuator. The effectiveness of this proposed control algorithm with smooth switching control has been demonstrated through experiments with various external loads.

The other advance research states on a nonlinear dynamic model of a PWM-driven pneumatic fast switching valve such as in Ref [4] the electro-magnetic, mechanical and fluid subsystems of the valve are investigated, including their interactions. Unknown parameters are identified using direct search optimization and model.

The difficulty of this work is that the test has done on rotary actuator. Rotary pneumatic actuator use in this experiment is of rack and pinion type which consists of two cylinders with rack assemble move in opposing direction to drive the pinion. This configuration poses a problem due to parametric variation of two cylinders. Gains have to be adjusted individually for each cylinder.

2. System description

2.1 Layout of the experimental devices

The layout of the experiment device of on-off solenoid valve is shown in fig. 1 consists of

1. Controller PC, DAQ card
2. Solid-state relay
3. 3/2 solenoid-pilot operated valve
4. Pneumatic actuator, flow control valve, potentiometer, load assembly
5. Pressure regulator

A PC connected accompanied with National Instruments multi-function PCI-6221 DAQ card with LabView Real-time operating system is applied as a controller and to get the experiment data. PWM signal was generated using DAQ onboard counter and solid state relay use as electronic switch. Two unmodified solenoid-pilot operated directional control valve with three ports and two positions was used to control the SMC CDRQB 40 rotating pneumatic actuator with built-in throttle valve which act as a low-pass filter for decrease damping and decrease vibration [1] at both end as shown in pneumatic circuit in fig. 2. Solenoid of each valve indicated as Y1 and Y2 as shown in fig. 2. Valve selection is base on value and availability for they are typical pneumatic solenoid valve used widely in industrial. Pressure regulator (SMC ARJ210) with operating range between 2 to 7 bar was used to control pressure at input port of both 3/2 valves. Actuator output shaft was coupled with single-turned potentiometer with output voltage range of –1 to 10 volt for position measurement. With LabView built-in low-pass filter functional block diagram used in controller program measured position was within ±0.02 volt resolution. Analog signal was sampling by PCI-6221 on-board 16 bit analog to digital converter. Controller program was written in LabView software. Block diagram of components is shown in fig. 3

The model of servo valve can roughly following Ref. [5] then apply the control law that we will discuss soon in next sub section

3. Controller design

3.1 PWM control method

PWM control with 3/2 way on-off valves instead of servo valves is used in many researches for accurate position control. In this system PWM is used with a frequency of 20 Hz, which is supported by the on-off valves. In PWM control, according to the feedback results duty cycle of PWM is controlled as two valves are excited reversely. Duty cycle's value is maximum 0.9 and minimum 0.1, which means on-off valves do not get to open to the air or to the supply pressure during all period of PWM.

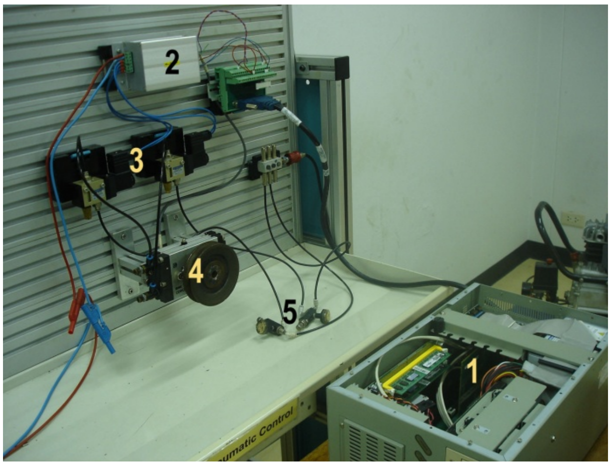

Fig. 1 Pneumatic system test rig

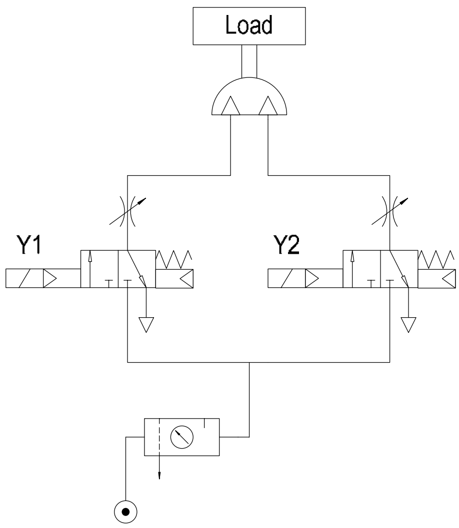

Fig. 2 Pneumatic circuit use in this research

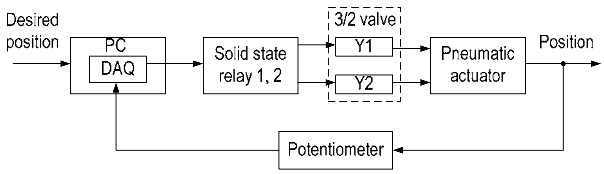

Fig. 3 Schematic diagram of the control system

3.2 Control law

The conventional Proportional-Derivative-Integral (PID) control scheme as shown in Eq. (1)

was used in this experiment with some modification due to on-off nature of solenoid valve.

$$u = K_p e + K_v \dot{e} + K_i \int e dt \qquad (1)$$

Where e is the error between desire position and actual position. The control system is operated in two scenarios where actuator moves in each direction.

In case of the actuator move in counter-clockwise direction then we define the control signal

$$\begin{cases} u_1 = |u| \\ u_2 = 0.9 \end{cases} \qquad (2)$$
$$sgn(u) = 1$$

Where u is the control signal calculated from Eq. (1) with maximum value of 0.9, u_1 and u_2 is the duty cycle command range from 0 to 1 of each solenoid.

On the other hand when actuator move in clockwise direction we have

$$\begin{cases} u_1 = 0.9 \\ u_2 = |u| \end{cases} \qquad (3)$$
$$sgn(u) = -1$$

From the above control scheme, control signal sign determined which of two solenoids will turn on. For example in the beginning of motion the position error is large and velocity error is small result in large proportional term and small derivative term sign of control signal will be "+". One solenoid is full on and the other switching. When actuator reach set point with high velocity position error become small and velocity error become large vice versa sign of u will become "—" which act as braking and actuator will slow down.

PID control scheme as in Eq. (1) and valve control strategy as in Eqs. (2) and (3) with PWM frequency of 40 Hz was used for the experiment and the corresponding result was shown in section 4.

4. Experiment and result

In this experiment, the reference inputs are set to be 5 volt and 9 volt. Square wave form with 20 peaks and 0.5 Hz frequency was used as test input. Control loop written in LabView software operated at 1000 Hz sampling rate. Responses are measured and steady-state error of actuator position for each input peak was observed.

We show the result from two difference input voltage and the test No.1 is shown in fig. 4 with the following parameters:

Step input 5v

Input pressure = 5.5 bar

Kp = 0.32 Kv = 0.17 and 0.1 Ki = 0.0023

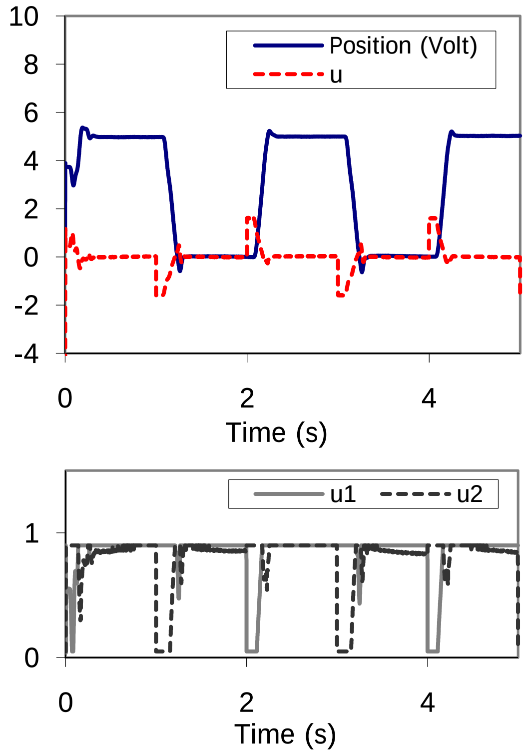

Fig. 4 Response of actuator with 5-volt step input

The other results from test No.2 is shown in fig.5 with following parameters:

Step input 9v

Input pressure = 5.5 bar

Kp = 0.32 Kv = 0.13 and 0.08 Ki = 0.0023

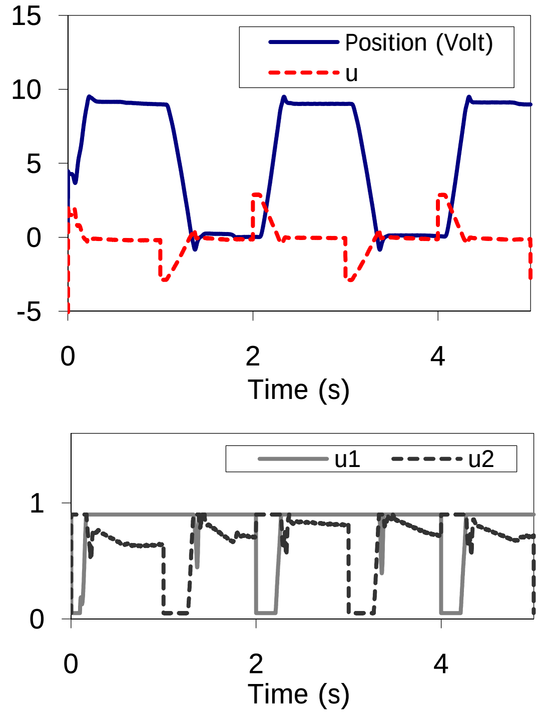

Fig. 5 Response of actuator with 9-volt step input

From figs. 4 and 5 time delay between initiation of step command and actuator actual movement is observed to be 80 ms. The experiment results give us that the maximum steady state error is about 3%, the rise time is 0.2s and settling time of 0.3s is achieve. The Overshoot of 4% was observed for 5-volt-step-size input and 5.5% for 9-volt-step-size input. The overshoot seen from both responses is due to compressibility of air and time delay results from friction of valve spool which does not realized in control algorithm.

5. Conclusion

In this paper, PID with PWM closed loop control of a rotating pneumatic actuator was discussed and experiment result was shown. The result show satisfactory performance and minimal steady-state error with specific set of gain for each reference input step size. However, pneumatic system has high degree of nonlinearity which cannot be completely compensate by PID control algorithm thus further investigate in system behavior is required if more performance is to be realized. With further research in more advance control scheme and knowledge of solenoid characteristic would see more application of on-off solenoid in place of servo valve in low-load moderate-accuracy task.

6. References

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