BEN19

Go Back

Design and Simulation of PD and PID Controller for Hybrid Actuator

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Abstract

The development of new and more effective methods of hybrid actuator is more and more increasingly done to produce optimal efficiency and performance outputs. In this paper, the system architecture and control of a new hybrid system which is the combination of the motion of DC motor and pneumatic motor transmitting power through a set of gear box to the output shaft is proposed. The classical controllers of PD and PID controller were applied to the rotational speed control of the proposed system. The MATLAB simulation is employed to investigate and evaluate the system performance when applying PD and PID controllers. Each type of speed controller was tested at no-load situation. Simulation results have shown that PD and PID controllers have given the similarly performance output but they are not good enough since both the DC motor and pneumatic motor runs at the different speed.

Keyword: hybrid actuator, PD controller, PID controller, simulation

1. Introduction

Nowadays, applications of hybrid systems can be found almost everywhere in the engineering field, especially, in manufacturing and automation industries. From the theoretical concept of hybrid system, hybrid system is the system that combines the motions of at least two characteristically different energy sources to produce the output. The development of new and more effective methods of hybrid actuator is more and more increasingly done to produce optimal efficiency and performance outputs. Many new actuation methods have been proposed while each type of actuator has different advantages and drawbacks that challenge the researchers to continuously develop new hybrid actuators.

As the two common widely used actuators in a variety of industrial applications are pneumatic and electric motors. The pneumatic motors generally offer numerous advantages such as cleanliness, low cost, high ratio of power to weight, east to maintain, safe, anti explosion, long working life and hard work loading. However the control accuracy is affected badly by nonlinear characteristics as the system drawback [1], [2]. On the other hand, the advantages of electric motors are precise control, portability, and cleanliness. However, the electric motors also suffer from the drawbacks of large size-to-torque ratio, limited range of power transmission mechanics and proneness to environmental hazards such as dirt, fire, and moisture [3]. To overcome the disadvantage of imprecision control of pneumatic motor, combining the high power-to-weight ratio and high speed of pneumatic motors with ease and precise control of DC motor can be performed. In this study, the system architecture and control of a new hybrid system which is the combination of the motion of DC motor and pneumatic motor is proposed.

The two main purposes of this study are to propose a novel design of hybrid actuator and to evaluate control performance of the hybrid actuator when applying the classical control methods; PD and PID controllers. The following sections are organized as follows: the introduction to system of the designed hybrid actuator is described in Section 2, the system dynamics is analyzed in Section 3, the speed control algorithms are proposed and analyzed in Section 4, the simulation results are also shown and discussed in Section 4 and the conclusion is stated in Section 5.

2. Hybrid Actuator System Architecture

The novel design of hybrid actuator aims to overcome the disadvantage of imprecision control of pneumatic motor and also takes the advantages of high power-to-weight ratio and high speed of pneumatic motors with ease and precision control of DC motor. The powers of both motors are transmitted simultaneously through a single output shaft rotating at the same speed level of electric and pneumatic motors. This system is able to generate high torque while maintain speed constantly. See Figures 1.

Go Back

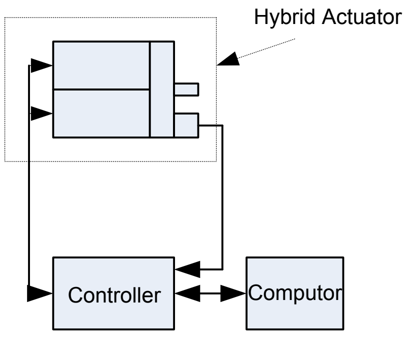

Figure 1: The Architecture of Hybrid Actuator System.

In the developed system, the specification of DC motor used is 60w, 3000 rpm, 24 volt, 3.9 A. and 4000 rpm maximum speed. On the other hand, the vane-type pneumatic motor is used with a proportional valve (Festo, MPYE-5-1/8) in order to control the rotational speed of a pneumatic motor.

2.1 Mathematical model of DC motor

The transfer function of a DC motor from input voltage, $v_i(s)$ to the output angular velocity, $\omega(s)$ is determined.

$$G(s) \;=\; \frac{\omega(s)}{v_i(s)} \;=\; \frac{k_m}{\tau s+1} \quad (1)$$

Where $G(s)$ = Transfer function from input voltage and output angular velocity.

$\omega(s)$ = Output angular velocity (rpm.).

$v_i(s)$ = Input voltage (v.).

k_m = Sensitivity of the DC motor.

τ = Time constant of the DC motor (s).

2.2 Mathematical model of Pneumatic motor

The pneumatic motor is modeled with the system time constant (τ), the sensitivity (k_n) and delay time (T) as following:

$$G(s) \;=\; \frac{k_n}{\tau s+1}e^{-Ts} \quad (2)$$

Where k_n = Sensitivity of the pneumatic motor.

τ = Time constant the pneumatic motor (s).

T = Time delay (s).

3. Speed control of hybrid actuator

In this study, both the classical control; PD-control and PID-control are applied to test and evaluate the performance of speed control of the proposed hybrid actuator.

3.1 PD-Controller

One of the frequently used controllers in control systems is the proportional–derivative (PD) controller. The main advantage of the PD controller is that it can easily be implemented. On the other hand, the performance obtained from PD controllers is not satisfying for the applications with high order [4]. The general block diagram is shown in Figure 2.

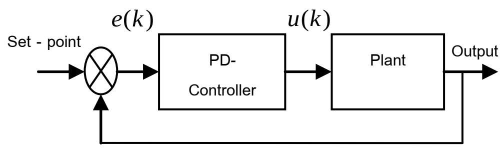

Figure 2: The general block diagram of PD-Controller.

The mathematical model of the PD-Controller can be expressed as:

$$u(k) \;=\; k_p e(k) + k_d \frac{de(k)}{dt} \quad (3)$$

Where $u(k)$ = actuating signal.

$e(k)$ = error signal.

k_p = gain of the proportional controller

k_d = gain of the derivative controller

The block diagram of the PD-controller of the proposed system is shown as Figure 3. The terms $k1$ and $k2$ are the relative gains.

3.1.1 Design of gains k_p, k_d, k_1 and k_2 of the PD-controller

The system is implemented on MATLAB simulation as shown in the block diagram illustrated in Figure 3.

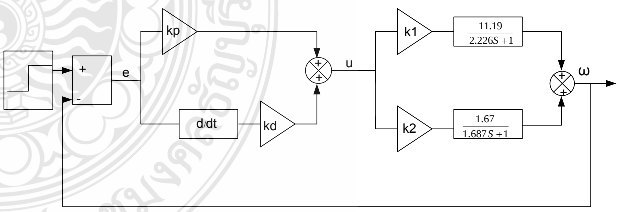

Figure 3: Block diagram of the PD-controller used in MATLAB simulation

The values of gain k_p, k_d, k_1 and k_2 used in the simulation by MATLAB at four different speeds; 500 rpm,1000 rpm, 1500 rpm and 2000 rpm, are given in Table 1.

Go Back

Table 1: The optimal gain of the PD-controller

Gains	500 rpm	1000 rpm	1500 rpm	2000 rpm
k_p	515	500	515	550
k_d	0.95	0.95	0.95	0.95
k_1	0.17	0.17	0.17	0.17
k_2	1	1	1	1

3.1.2 Simulation Result of PD-Controller

The graphs showing the relationship between speed in rpm and time of PD controller at 500, 1000, 1500, and 2000 rpm are shown in Figures 4 (a), 4 (b), 4 (c), and 4 (d), respectively.

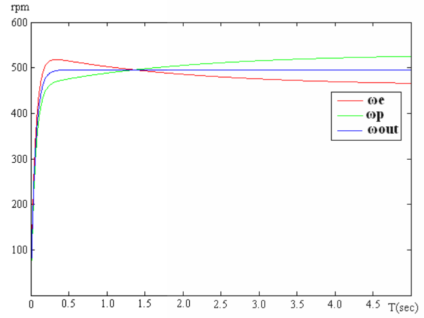

Figure 4(a): Simulation result at 500 rpm.

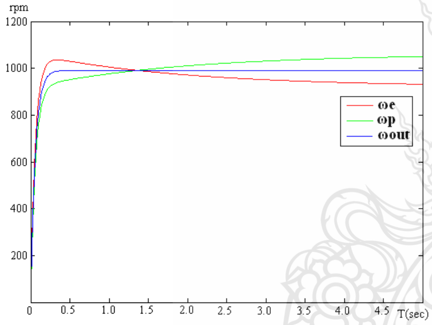

Figure 4(b): Simulation result at 1000 rpm.

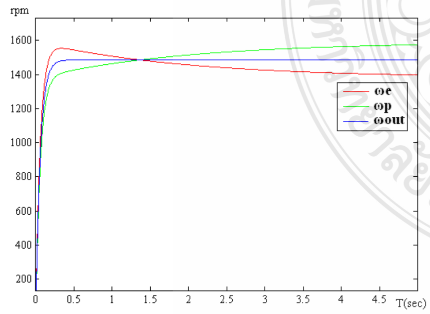

Figure 4 (c): Simulation result at 1500 rpm.

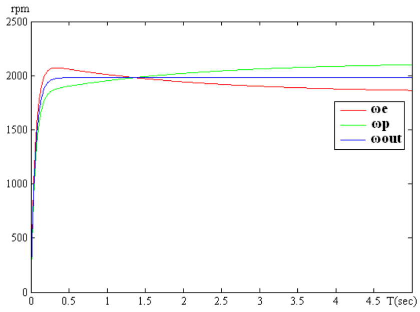

Figure 4(d): Simulation result at 2000 rpm.

From the Figure 4(a), the graph illustrates that at the initial starting period, the DC motor has higher speed $(\omega_e = 270 \text{ rpm})$ than the pneumatic motor $(\omega_p = 230\text{ rpm})$. After 1.5 seconds, on the other hand, the speed of the pneumatic motor $(\omega_p = 270\text{ rpm})$ is higher than the DC motor $(\omega_e = 240 \text{ rpm})$ However, whatever the speed of each motor is, the speed at shaft axis (ω_{output}) remains still approximately 500 rpm.

Similarly for the other three experiments at 1000 rpm, 1500 rpm and 2000 rpm, the graph of each experiment shows a similarity of the characteristic between DC motor and pneumatic motor in which at the initial period, the DC motor has a higher speed than the pneumatic motor, but after 1.5 seconds, the speed of pneumatic motor becomes higher than the speed of DC motor. However, at the end, the speed at the shaft axis is identical with the speed at the set point of each experiment. See the Figures 4(b), 4(c) and 4(d).

3.2 PID-Controller

Typically, the PID controller includes a proportional term, integral term and derivative term. The proportional term is used to adjust the output of controller according to the magnitude of error. The integral term is used to remove the steady state error of the controlled system and improve the steady state response. The derivative term is used to predict the trend of error and improve the transient response of the controlled system. The PID controller is enough to control up to second order processes. Because the structure of PID controller is simple, it is the most extensive control method design used in industry. The PID controller is mainly involved with selection of appropriate proportional gain (KP), integral gain (KI), and differential gain (KD) to achieve the designed control performance. The general PID controller system block diagram is shown in Figure 5.

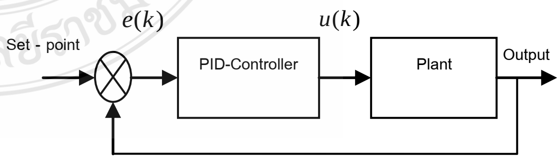

Figure 5: General block diagram of PID-controller.

The discrete-time PID-controller can be expressed as [5]

$$u(k) = u(k-1) + \Delta u(k) \quad (4)$$

$$\Delta u(k) = k_p[e(k) - e(k-1)] + k_i Te(k) + k_d[e(k-1) + e(k-2)] \quad (5)$$

Go Back

Where $u(k)$ = actuating signal.

$\Delta u(k)$ = actuating signal change

$e(k)$ = error signal.

k_p = gain of the proportional controller

k_i = gain of the integral controller

k_d = gain of the derivative controller

T = Sampling time

3.2.1 Design of gains k_p, k_d, k_1, k_2 and k_i of the PID-controller

The system is implemented on the MATLAB simulation as shown in the block diagram illustrated in Figure 6.

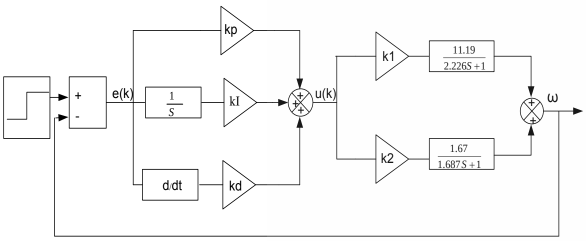

Figure 6: Block diagram of the PID-controller used in MATLAB simulation

The values of gain k_p, k_d, k_1, k_2 and k_i used in the simulation by MATLAB at three different speeds, are given in Table 2 .

Table 2: The gains of the PID-controller

Gains	500 rpm	1000 rpm	1500 rpm	2000 rpm
k_p	500	500	515	515
k_i	0.5	0.5	0.5	0.5
k_d	0.8	0.8	0.85	0.90
k_1	0.17	0.17	0.17	0.17
k_2	1	1	1	1

3.1.2 Simulation Result of PID-Controller

The graphs showing the relationship between speed in rpm and time of PID controller at 500, 1000, 1500, and 2000 rpm are shown in Figures 7 (a), 7 (b), 7 (c), and 7 (d), respectively.

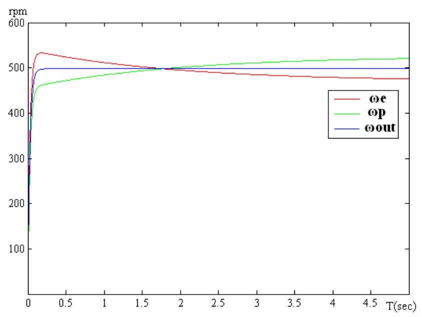

Figure 7(a): Simulation result at 500 rpm.

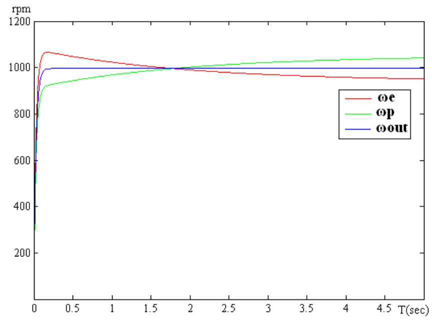

Figure 7(b): Simulation result at 1000 rpm.

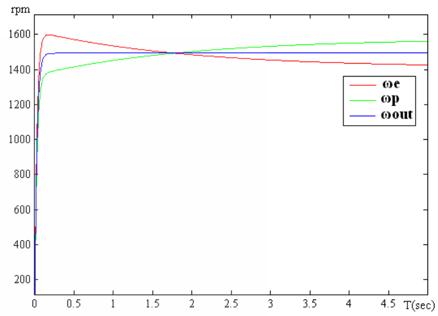

Figure 7(c): Simulation result at 1500 rpm.

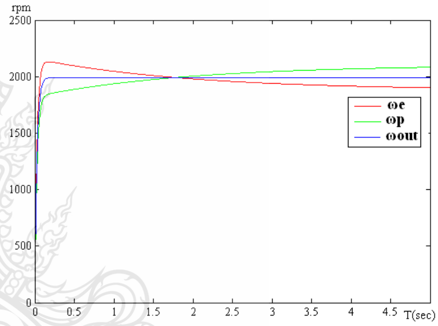

Figure 7(d): Simulation result at 2000 rpm.

Figures 7 (a), 7 (b), 7 (c), and 7 (d) show the simulation results at different speeds by using PID controller. The results are similar to the results obtained by using PD controller. Finally, it can be concluded that by using PD and PID controller, the speed of DC motor is higher than the speed of pneumatic motor at the initial stage, then after 1.5 seconds, the speed level of pneumatic motor becomes higher than the speed of DC motor. However, at the end, the speed at shaft axis is equal to the speed at the set point.

4. Conclusion

In this paper, the successful development of hybrid actuator was presented. The actuator is the combination of the motion of DC motor and pneumatic motor transmitting power through a set of gear box to the output shaft. The classical controllers of PD and PID controller were applied to the rotational speed control of the proposed system. Each type of speed controller was tested at no-load situation to investigate and evaluate the system performance. Simulation results have shown that PD and PID controllers have given the similarly performance output but they are not good enough since both the DC motor and pneumatic motor runs at the different speed. In the further work, the speed control performance would be examined with other controller types and the performance output with load circumstance would be also investigated.

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Go Back