The Control of the Pneumatic Actuator Using Dahlin Algorithm

K. Kawaguchi, J. Endo, H. Shibasaki, R. Tanaka, Y. Hikichi and Y. Ishida

***Abstract*—These In this paper, the control of the pneumatic actuator using Dahlin algorithm is proposed. Dahlin algorithm has problem which cause a steady-state error by an input-side disturbance for an integrator plant with time delay. In addition, it has problem which not ensure follow-up to a response model by parameter error of controller. To solve these problems, we introduce discrete-time IMC and iterative least squares technique. Our proposed method can remove a steady-state error caused by an input-side disturbance for an integrator plant with time delay by introducing discrete-time IMC and ensure follow-up to a response model by introducing iterative least squares technique. In the simulation, it is shown that the proposed method has a superior performance for an integrator plant with time delay. Furthermore, by applying the proposed method to a pneumatic actuator, the effectiveness of the method is examined and confirmed.**

***Index Terms*—Dahlin algorithm, discrete internal model control, auto-tuning.**

I. Introduction

Many physical systems, such as thermal processes, chemical processes, and long transmission lines in pneumatic systems etc. contain time delays. Time delays cause systems to destabilize or to degrade their feedback performance.

Conventional controllers, like the PID controllers [1] could be used when the dead-time is small, but they show poor performance when the process exhibits long time delays because a significant amount of detuning is required to maintain closed-loop stability. Various control methods such as Smith compensator [2]-[4] and IMC [5] (Internal Model Control) were proposed as a method of controlling a system with time delays [6]. Eric Dahlin [7] in 1968 proposed a control algorithm for a system with time delays. Zhang Zhi-Gang et al [8] analyzed Dahlin algorithm in detail. This algorithm has advantage that is follow-up to a response model. However, a steady-state error is caused by an input-side disturbance for an integrator plant with time delay in Dahlin algorithm. Furthermore, when estimated plant parameters have errors, the plant output is different from that of the model. To solve these problems, we introduced discrete-time IMC [9] into Dahlin algorithm, because discrete-time IMC can eliminate a steady-state error caused by an input-side disturbance for an integrator plant with time delay. Besides we introduced iterative least squares technique [10] which is one of the auto-tuning method [11]-[13] or system identification [14], [15] into the algorithm to correct an error of a plant, because this technique can calculate correct plant parameter from plant input and output. The advantage of the proposed method makes output conform to a desired response for an integrator plant with long time delay and parameter error.

In the simulation, it is shown that the proposed method has a superior performance for an integrator plant with time delay. Furthermore, by applying the proposed method to a pneumatic actuator that has an integrator plant with long time delay, the practicality of the proposed method is confirmed.

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II. Dahlin Controller

$$G(s)e^{-Ls} = \frac{1}{Ts}e^{-Ls} \tag{1}$$

$$G(z)z^{-d} = \frac{b}{1-az}z^{-d} \tag{2}$$

The equation (1) shows a controlled plant. An equation (2) is the plant discretized by zero-order-hold at sampling time T_s. where L is the time delay, T is the time constant and $d=L/T_s$ is integer.

$$\phi(s) = \frac{1}{T_m s+1}e^{-Ls} \tag{3}$$

A response model is expressed by (3). An equation (4) is the response model discretized by zero-order-hold at sampling time T_s. where Tm is the time constant.

$$\phi(z) = \frac{(1-\alpha)z^{-(d+1)}}{1-\alpha z^{-1}} \tag{4}$$

where $\alpha = e^{-T_s/T_m}$. From (2), (4) Dahlin Controller is as (5).

$$\begin{aligned} C(z) &= \frac{1}{G(z)z^{-d}}\frac{\phi(z)}{1-\phi(z)} \\ &= \frac{1}{G(z)z^{-d}}\frac{(1-\alpha)z^{-(d+1)}}{1-\alpha z^{-1}-(1-\alpha)z^{-(d+1)}} \end{aligned} \tag{5}$$

III. Discrete Internal Model Control

The target value response $Y_D(z)/R_D(z)$ and disturbance response $Y_D(z)/D_D(z)$ in discrete-time IMC are as (6).

$$\left.\begin{aligned} \frac{Y_D(z)}{R_D(z)} &= \frac{C(z)G(z)z^{-d}}{1+M(z)G(z)z^{-d}-M(z)G_m(z)z^{-d}} \\ \frac{Y_D(z)}{D_D(z)} &= \frac{(1-M(z)G_m(z)z^{-d})G(z)z^{-d}}{1-M(z)G_m(z)z^{-d}+M(z)G(z)z^{-d}} \end{aligned}\right\} \tag{6}$$

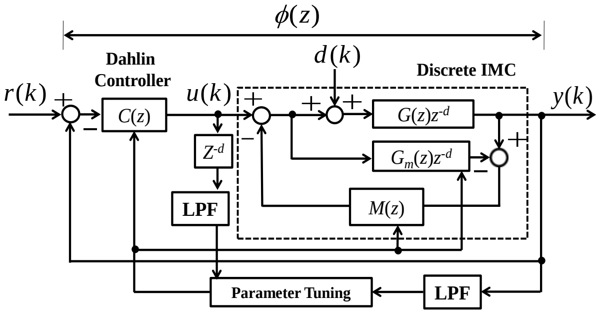

Fig. 1. Block diagram

where $M(z)$ is a disturbance compensator and $G_m(z)z^{-d}$ is a plant model.

When $G_m(z)$ equals to $G(z)$, (6) is written by (7). From (7), $M(z)$ is as (8).

$$\begin{cases} \dfrac{Y_D(z)}{R_D(z)} = C(z)G(z)z^{-d} \\ \dfrac{Y_D(z)}{D_D(z)} = (1 - M(z)G(z)z^{-d})G(z)z^{-d} \end{cases} \tag{7}$$

$$\begin{cases} M(z) = \dfrac{z-a}{z} \times \dfrac{\beta_1(z-1)+\beta_0}{\{\lambda(z-1)+1\}^2} \\ \beta_0 = \dfrac{1}{b}, \beta_1 = \dfrac{2\lambda + d + 1}{b} \end{cases} \tag{8}$$

IV. ITERATIVE LEAST SQUARES TECHNIQUE

$$\begin{cases} y(k-d) = Z^{\mathrm{T}}(k-d)\theta \\ \theta^{\mathrm{T}} = \begin{bmatrix} a & b \end{bmatrix} \\ Z^{\mathrm{T}}(k-d) = \begin{bmatrix} y(k-d-1) & u(k-d-1) \end{bmatrix} \end{cases} \tag{9}$$

From (2) and (9). (10) is algorithm of iterative least squares technique. An estimated value $\hat{\theta}(k-d)$ of θ at sampling time k-d is obtained by applying (10) to (9).

$$\begin{cases} \hat{\theta}(k-d) = \hat{\theta}(k-d-1) \\ \qquad + \dfrac{P(k-d-1)Z(k-d)y(k-d)}{1+Z^{\mathrm{T}}(k-d)P(k-d-1)Z(k-d)} \\ \qquad - \dfrac{P(k-d-1)Z(k-d)Z^{\mathrm{T}}(k-d)\hat{\theta}(k-d-1)}{1+Z^{\mathrm{T}}(k-d)P(k-d-1)Z(k-d)} \\ \hat{P}(k-d) = P(k-d-1) \\ \qquad - \dfrac{P(k-d-1)Z(k-d)Z^{\mathrm{T}}(k-d)P(k-d-1)}{1+Z^{\mathrm{T}}(k-d)P(k-d-1)Z(k-d)} \end{cases} \tag{10}$$

V. SIMULATION STUDY

In this section, we show simulation result of the proposed method. A unit step set-point was introduced at time t = 0[sec]. To reduce the influence of the manipulated value in start, we used *Low Pass Filter*. The transfer function of *LPF* was decided by empirical rule. A plant, a plant model and a response model are (11), (12) and (13), respectively. The initial value of θ is based on G_m. λ is 1050 in $M(z)$. A load disturbance $D(s)$ = -0.1/s was introduced at time t =150[sec]. Furthermore, we introduced +100% error to the time constant T to confirm the robustness of the proposed method. Fig.1 is a block diagram of the proposed method. Simulation results are shown in Fig. 2 and Fig. 3.

$$G(s)e^{-Ls} = \frac{1}{Ts}e^{-0.7s}, \quad T = 0.96 \tag{11}$$

$$G_m(s)e^{-Ls} = \frac{1}{0.96s}e^{-0.7s} \tag{12}$$

$$\phi(s) = \frac{1}{10s+1}e^{-0.7s} \tag{13}$$

$$LPF = \frac{5.0\times10^{-5}}{5.0\times10^{-4}s+1} \tag{14}$$

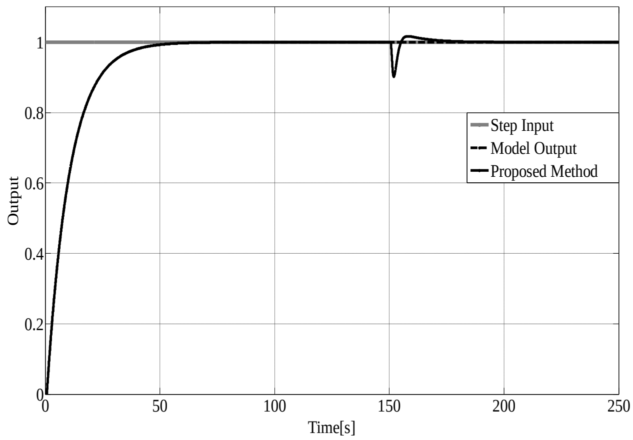

Fig. 2. Nominal System

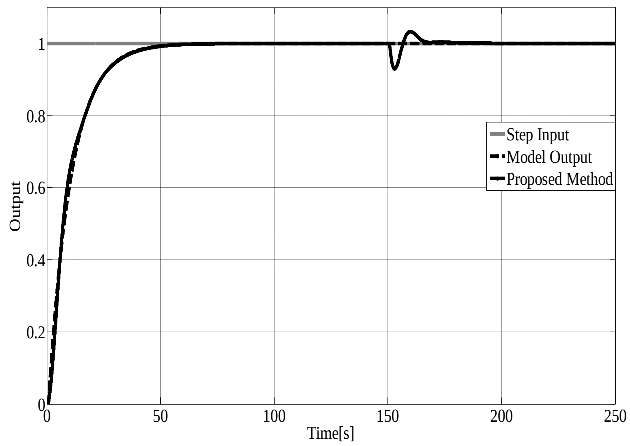

Fig. 3. Robust System (+100% error in T)

VI. EXPERIMENT

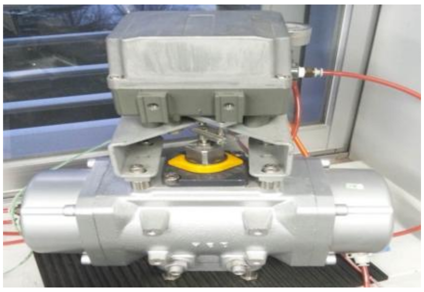

Fig. 4. Pneumatic Actuator

In this section, by applying the proposed method to a pneumatic actuator, the practicality of this method was confirmed. The situation is the same as simulation. The transfer function of a pneumatic actuator is (15). Fig.4 is a pneumatic actuator. The actuator moves the range of 0 - 90 degrees, and the angle is detected by a sensor and outputs -10 - 10[V] depending on an angle. Air pressure is 0.4 [Mpa].

$$G(s)e^{-Ls} = \frac{1}{0.96s}e^{-0.7s} \tag{15}$$

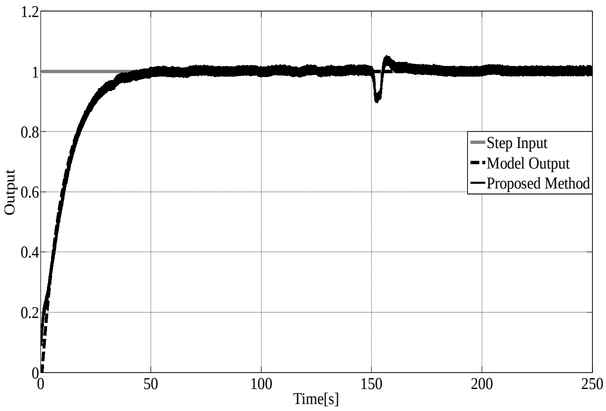

Fig. 5. Output of the pneumatic actuator

VII. Conclusion

In this paper, we have proposed a construction method of control system for an integrator plant with time delay. The proposed method could remove a steady-state error caused by an input-side disturbance for an integrator plant with time delay. Furthermore, it could ensure follow-up to a response model. In this experiment, it was shown that our proposed method is practicable.

Future work is to compensate against an error in time delay by use of a predicted state feedback.

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