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APPLICATION OF ADAPTIVE CONTROLLER TO WATER HYDRAULIC SERVO CYLINDER

Hidekazu TAKAHASHI*, Kazuhisa ITO** and Shigeru IKEO**

* Division of Science and Technology, Graduate school of SOPHIA University
7-1 Kioicho, Chiyoda-ku, Tokyo, Japan
(Tel: +81-3-3238-3873, E-mail: tak-hide@sophia.ac.jp)

** Dept. of Mech. Eng., Faculty of Science and Technology
SOPHIA University
7-1 Kioicho, Chiyoda-ku, Tokyo, Japan
(Tel: +81-3-3238-3606, E-mail: kazu-ito@me.sophia.ac.jp, s_ikeo@sophia.ac.jp)

ABSTRACT

Water hydraulic servo system is an attractive system source for its environmental safety. In this system, the problem for precise control is the uncertainties and/or the unmodeled dynamics which includes parameter variations depending on driving conditions and nonlinearity of system e.g. friction force, flow equation and so on. In this paper, we discuss the control performance of adaptive positioning controller for water hydraulic servo cylinder. This controller method aims to reduce the tracking error tend to zero for given reference signal asymptotically and ensures controller parameters keep being bounded. Based on the least square method, parameter update law is given and adaptive tracking controller is constructed. The robustness is examined experimentally for supply pressure changes and load fluctuations.

KEY WORDS

Water hydraulic system, Servo valve, Cylinder, Adaptive control, Position control

INTRODUCTION

In recent years manufacturers and users have been requested to take much care of mineral oil. Hence the water hydraulic technique using pure tap water as a pressure medium became a hot issue again with an increase of our concerns for global environment problems and also with the technological advances on materials, machining and lubricity. This was also motivated by its high safety for fire hazard in production plant, easy availability and low cost. Water hydraulic system now has been applied to food processing, semi-conductor industry, forest industry, atomic power industry and so on [1], [2]. Among them, the PID control strategy is mainly used as a control system design for its simplicity and intuitive interpretation of control parameters. However, comparison with conventional oil hydraulics, the precision of positioning and rotational velocity control of water hydraulics are relatively lower. This is due to the uncertainties including physical parameter changing, unmodeled dynamics and disturbance. In water hydraulic case, fluctuation of load and supply pressure lead to parameter change while the friction, the leakage flow and the dead zone work as disturbance. As a result, PID controller is hard to accommodate such uncertainties [3]. This motivates to apply adaptive control method to compensate such uncertainties and make the closed-loop system to keep the specified performance and be more robust.

In this paper, the nominal system is assumed to be linear, and we discuss the positioning controller design for water hydraulic cylinder drive system using adaptive control theory. More specified, based on the general least square method or the fixed trace method as a parameter update law, we construct adaptive tracking controller, and examine its robustness for parameter changes.

WATER HYDRAULIC SYSTEM

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A schematic diagram of the water hydraulic servo system that forms the basis of this study is shown in Figure 1. The experimental water hydraulic servo system consists of a water hydraulic power unit, double rods type water hydraulic cylinder and water hydraulic servo valve. The cylinder connected to the load cart set up horizontally. The position of the cylinder detected by the linear encoder on the cart is taken into the PC through the digital counter. The control input u generated in PC is sent to a servo amplifier. Primary specification is shown in Table 1. The control system designed in the next section is implemented on the dSPACE, and the experiment is performed.

Table 1 Specification of the experimental set-up

cylinder (double rods type)	f25×f14×300st.
load	100 [kg], max.
water hydraulic power unit	14.0 [MPa], max.
servo valve	20 [L/min] (@ 7[MPa])
working fluid	30±1[deg C] (tap water)
linear encoder	320 [mm] : stroke 0.5 [μm] : resolution

CONTROLSTRUCTURE

A precise modeling of water hydraulic cylinder control system is a very difficult problem due to its inherent highly nonlinearities and uncertainties. Especially in initializing the experiment, it is necessary in this study to set the servo valve spool at a neutral position by hand and this routine makes the dead zone be differed value each time. Thus in this study, we introduced a closed loop control system as a pre-feedback from cylinder

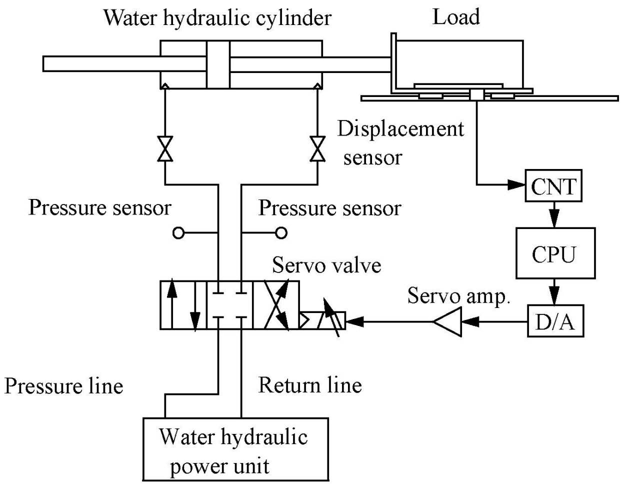

Figure 1 Water hydraulic servo system

reference position $x(t)$ to measured cylinder position $y(t)$ shown in Figure 2. Therefore we can ignore this nonlinearity including the spool position drift and we can treat it as a new plant. We choose the pre-feedback gain as K_P=0.7[V/mm] fromexperiments.

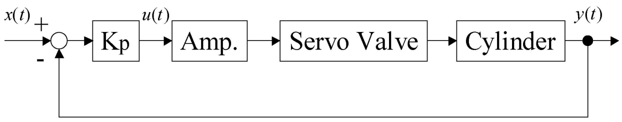

Figure 2 Block diagram of controlled system

DISCRETE TIME ADAPTIVE CONTROLLER

We consider following discrete linear time invariant SISO system.

$$y(k) = \frac{z^{-d}B(z^{-1})}{A(z^{-1})}u(k) \tag{1}$$

where $y(k)$ and $u(k)$ are the measurable input and output respectively, and $A(z^{-1})$ and $B(z^{-1})$ are polynomials in the unit delay operator of the form

$$A(z^{-1}) = 1 + a_1 z^{-1} + \cdots + a_n z^{-n}$$
$$B(z^{-1}) = b_0 + b_1 z^{-1} + \cdots + b_m z^{-m}, \quad b_0 \neq 0$$

The orders n and m as well as the time delay $d \geq 1$ are assumed to be known. In this study, n=2, m=1 and d=1. For the pole assignment of closed loop and the following Diophantine equation is employed [4], [5].

$$D(z^{-1}) = A(z^{-1})R(z^{-1}) + z^{-d}H(z^{-1}) \tag{2}$$

where

$$R(z^{-1}) = 1 + r_1 z^{-1} + \cdots + r_{d-1} z^{-(d-1)}$$
$$D(z^{-1}) = 1 + d_1 z^{-1} + \cdots + d_n z^{-n}$$
$$H(z^{-1}) = h_0 + h_1 z^{-1} + \cdots + h_{n-1} z^{-(h-1)}$$

In Eq.(2) the polynomial $D(z^{-1})$ defines the closed loop poles and in this study an appropriate choice is $D(z^{-1})=(1-0.1z^{-1})^2$. The design parameter $D(z^{-1})$ determines unique solution $R(z^{-1})$ and $H(z^{-1})$ through Eq.(2), and each degrees are

$$\deg H(z^{-1}) = n-1, \quad \deg R(z^{-1}) = d-1 \tag{3}$$

From Eq.(1) and (2), the following equation is derived as the nonminimal expression for a plant:

$$D(z^{-1}) y(k) = q^T f(k-d) \tag{4}$$

where

$$q^T = [b_0, (b_0 r_1 + b_1), \cdots, b_m r_{d-1}, h_0, h_1, \cdots, h_{n-1}]$$
$$f^T(k) = [u(k), u(k-1), \cdots, u(k-m-d+1), y(k), y(k-1), y(k-n+1)]$$

Given a reference input y_m, the output error equation is

$$D(z^{-1})\left[y(k+d) - y_m(k+d) \right] = 0 \tag{5}$$

From Eqs.(2) and (5), control input $u(k)$ is derived as follows.

$$u(k) = \frac{1}{b_0}\left[D(z^{-1}) y_m(k+d) - \bar{q}^T \bar{f}(k) \right] \tag{6}$$

where

$$q^T = \left[b_0, \bar{q}^T \right]$$
$$f^T(k) = \left[u(k), \bar{f}^T(k) \right]$$

When plant parameters are unknown in Eq.(6), we generate control input $u(k)$ as follows with adjustable parameters ($\hat{}$).

$$u(k) = \frac{1}{\hat{b}_0(k)}\left[D(z^{-1}) y_m(k+d) - \hat{\bar{q}}^T(k) \bar{f}(k) \right] \tag{7}$$

The overall block diagram of the discrete-time adaptive tracking control system is shown in Figure 3, where

$$\hat{B}_R(z^{-1}, k) = B(z^{-1}) \hat{R}(z^{-1}) - \hat{b}_0 \tag{8}$$

The stability proof of this scheme is given in [5] and [6].

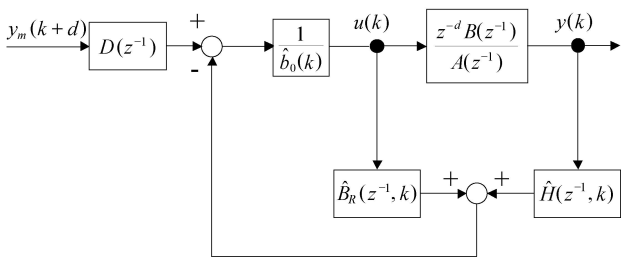

Figure 3 Discrete-time adaptive tracking control system

As a parameter update algorithm, we adopt the following recursive least square method with variable gain.

$$\hat{q}(k) = \hat{q}(k-1) - P(k-1) f(k-d) e_1(k)$$
$$P(k) = \frac{1}{l_1(k)} \cdot \left[P(k-1) - \frac{l_2(k) P(k-1) f(k-d) f^T(k-d) P(k-1)}{l_1(k) + l_2(k) f^T(k-d) P(k-1) f(k-d)} \right] \tag{9}$$

where

$$e_1(k) = \frac{-D(z^{-1}) y(k) + \hat{q}^T(k-1) f(k-d)}{1 + f^T(k-d) P(k-1) f(k-d)}$$
$$0 < l_1(k) \le 1,\ 0 \le l_2(k) < l,\ P(0) = P^T(0) > 0$$

If we choose $l_1(k)$=1, $l_2(k)$=1, then Eq.(9) gives general least square method. On the other hand, if we choose $l_1(k)$, $l_2(k)$ so that tr$P(k)$=tr$P(0)$=constant , then Eq.(9) gives fixed trace method [5].

EXPERIMENTAL RESULTS

In this chapter we examine and discuss the robustness of adaptive control for supplied pressure changes and load fluctuations. More specified, we adopt general least square method or fixed trace method as a controller parameter update law, and discuss its control performance. The initial values of adjustable parameters and gain-update matrix of adaptive controller are $q(0)=[1.5,0,0,0]^T$, $P(0)=10^{-6}I$, respectively, independent of the system information a priori, and I is a forth order identity matrix. Figure 4 and Figure 5 show experimental results of the position control and the position error in adaptive control with least square or fixed trace method. Experimental conditions are 5[MPa] of supplied pressure and 0[kg] of the mass of load. Figure 6 and Figure 7 are for case of the supplied pressure 5[MPa] and the mass of load 100[kg]. Figure 8 and Figure 9 are in the case of the supplied pressure 7[MPa] and the same load mass.

From Figure 5, Figure 7 and Figure 9, it is seen that the changes of load or supplied pressure have few effects on the control performance in adaptive control with both least square and fixed trace method. However in the case of the least square update law, steady state error remains for 5-10[s] and for 15-20[s] while position error is about 20μm for 10-15[s].

In order to make clear the reason, friction characteristics of the cylinder and flow characteristics of the servo valve are investigated experimentally. As for friction characteristics of the cylinder, the difference between positive and negative direction of the cylinder position is small, thus we conclude that the effect of friction can be nearly ignored. On the other hand, flow characteristics of the servo valve used in this experiment differs depending on the direction of the spool displacement, and the direction of the spool displacement is negative both for 5-10[s] and for 15-20[s]. Figure 10 shows the experimental flow characteristics of the servo valve used in this experiment where the data between -0.5[l/min] and 0.5[l/min] is omitted for the sensor resolution. This implies that the flow characteristic differs for the direction of spool displacement.

As mentioned above, it is seemed that steady state errors in Figure 4 to Figure 9 are caused by flow characteristics of the servo valve. The other reason is that the norm of gain-update matrix P in the general least square method decreases rapidly as time goes by, and as a result the adaptive controller parameters are hardly updated. On the other hand, in the case of the fixed trace method, the norm of gain-update matrix P is constant, and controller parameters are always updated effectively. Therefore position error is about 1μm for 0-20[s], and the effect of nonlinearity of the servo valve used in this experiment could be compensated.

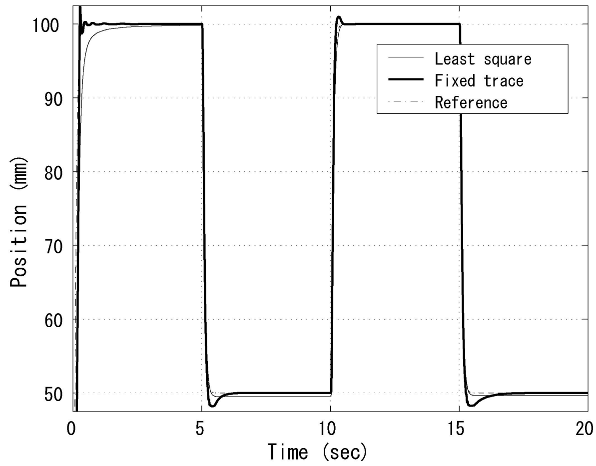

Figure 4 Experimental result: no load, supplied pressure 5[MPa]

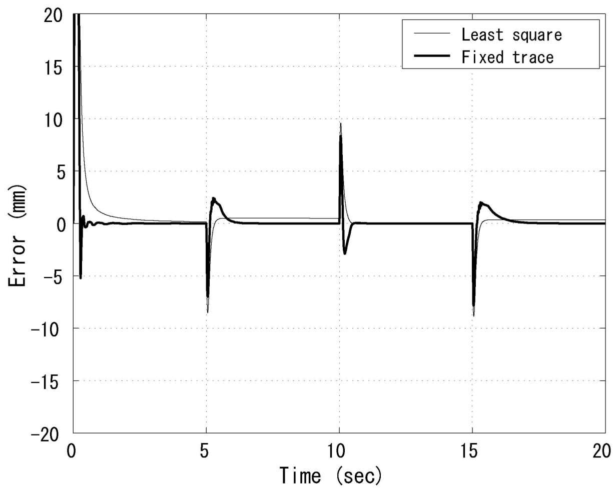

Figure 5 Experimental result (Error): no load, supplied pressure 5[MPa]

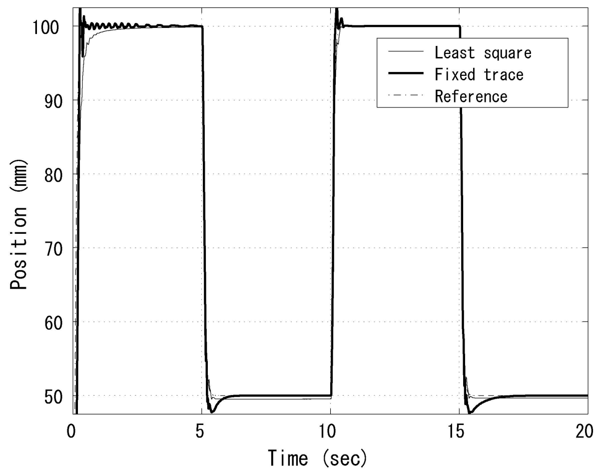

Figure 6 Experimental result: load 100[kg], supplied pressure 5[MPa]

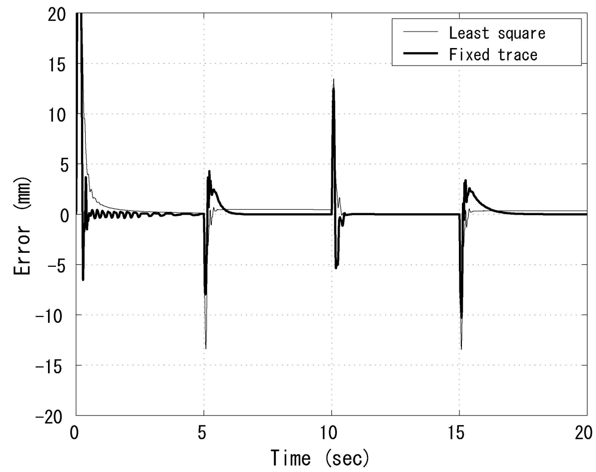

Figure 7 Experimental result (Error): load 100[kg], supplied pressure 5[MPa]

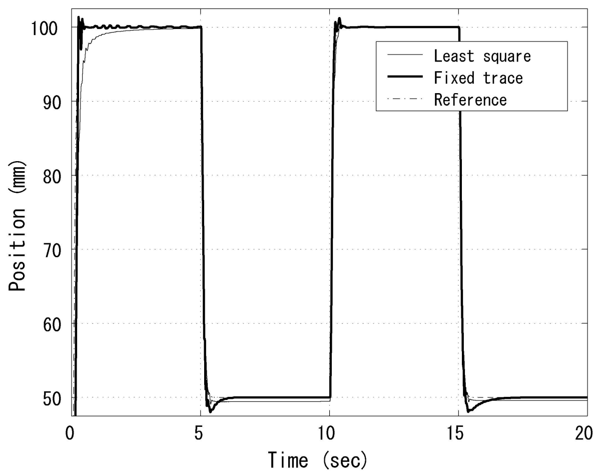

Figure 8 Experimental result: load 100[kg], supplied pressure 7[MPa]

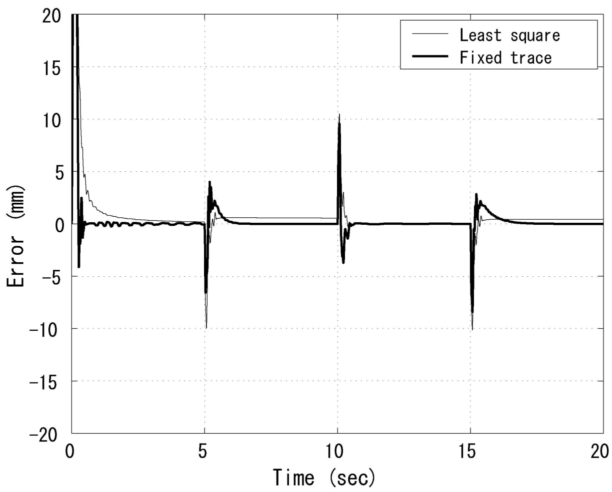

Figure 9 Experimental result (Error): load 100[kg], supplied pressure 7[MPa]

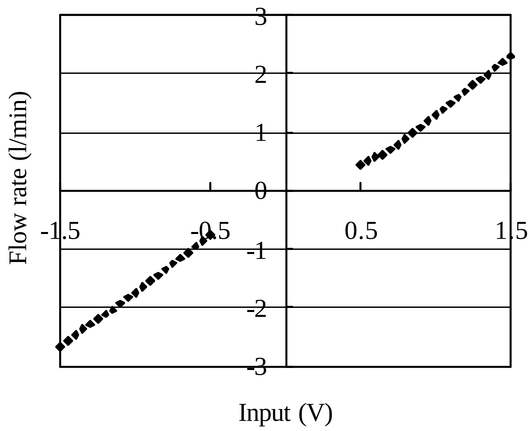

Figure 10 Experimental flow characteristics of the servo valve

CONCLUSION

In this research, the control performance of adaptive control strategy for water hydraulic cylinder was examined. It is shown experimentally that the adaptive controller has the robustness for supplied pressure changes and/or the load fluctuations by using fixed trace method as a parameter gain update law. As for the cylinder used in this experiment, the effect of friction is very small, therefore the system dynamics can be treated as almost linear. The experimental results show that the application of adaptive controller to water hydraulic servo system is practical.
We consider more simple adaptive control strategy as a future work and the application for water hydraulic motor.

REFERENCES

1. Trostmann, E., Water Hydraulics Control Technology, 1996, Marcel Dekker, Inc.
2. Trostmann, E., Fround, B., Olesen, B.H., and Hilbrecht, B., Tap Water as a Hydraulic Pressure Medium, 2001, Marcel Dekker, Inc.
3. Terasaka, D., Ito, K. and Ikeo, S., PID-Control of Water Hydraulic Servomotor System, Fifth JFPS International symposium, 2002, Vol. 1, pp.443-448.
4. Landau, Y.D., Adaptive Control, 1980, Marcel Dekker, Inc.
5. Goodwin, G.C. and Sin, K.S., Adaptive filtering Prediction and Control, 1984, Prentice-Hall.
6. Goodwin, G.C., Ramadge, P.J. and Caines, P.E., Discrete-Time Multivariable Adaptive Control, IEEE Trans., 1980, AC-25-3, pp.449-453.