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An AGMC Control Strategy for Electro-hydraulic Servo System

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Abstract

In view of the nonlinear electro-hydraulic servo system, this paper introduces an algorithm of generic model control based on input equivalent disturbance to design the controller, so as to improve its tracking ability for load. This controller is able to make self-adaptation feed forward compensation by making use of estimated input equivalent disturbance. Besides, it has advantages such as easy parameter setting and definite physical meaning. AGMC controller can also effectively track the time varying parameters of hydraulic servo system and unpredictable disturbance. According to simulation experiments, it's proved that AGMC control method is feasible and effective to enable nonlinear electro-hydraulic servo system to fulfilled self-adaptation. Therefore, this paper research has significant application values in engineering.

Keywords: servo system; tracking ability; input equivalent disturbance; AGMC controller; unpredictable disturbance.

1. Introduction

Recently, the development of industry has set higher requirement for the parameters and performance of position, speed as well as working load in Electro-Hydraulic Servo System[1]. That's why lots of advanced algorithms are applied to it [2]. Actually, complicated control system used in practical project application is nonlinear [3]. Therefore, algorithms like robust control[4] and self-adaptation control[5] are largely used in project practice. However, due to their complicated design for parameter and unclear application fields, a control theory based on general model is proved in practice and applied universally. In document No. [6], the author converted a general GMC second order curve equation to a standard second order curve equation and achieved a better control effect. But, GMC algorithm has its own disadvantages, especially when the model is oversized and mismatched together with interference. As a consequence, it won't work well. In view of this, Lee introduced compensation for control model, and Signal also brought forward a self-adaptation evaluation model parameters in real time so as to make self-adaptation control possible for general models[7]. In document No. [8], the author compensated GMC control algorithm with PID controller output by introducing input equivalent disturbance (IED). That is to integrate sources of system errors, namely model errors, time varying parameters, disturbance parameters and so on. Based on this, this paper introduces an algorithm of generic model control (AGMC). Experiments indicate that it can better track the load when inputting self-adaptation compensation of input equivalent disturbance (IED), which has significant meaning and promoted values.

2. Generic Model Control

To stimulate multiple-input and multiple-output nonlinear signal:

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$$\begin{cases} \dot{x}\{t\} = f(x,d,\theta) + g(x,d,\theta)u(t) \\ y(t) = h(x,\theta) \end{cases} \quad (1)$$

In the formula, each parameter has corresponding range, i.e. $x(t) \in R^n$, $u(t) \in R^m$, $y(t) \in R^m$, $d \in R^p$, $\theta \in R^1$; the nonlinear functions for variables x, d are $f(\cdot), g(\cdot), h(\cdot)$ respectively. There is a partial derivative of higher order in a row when x at some space. Meanwhile, the relative order of output variable is required to be 1. In this paper, $\bar{f}, \bar{g}, \bar{h}$ are used to represent non-ideal approximation models, for based on optional control (OC1), the solution of GMC can be obtained.

$$\begin{cases} (OC\ 1)^{\min \int_0^t [a(x,u,d)^T \bullet w \bullet a(x,u,d)dt} \\ \qquad st: | u | \leq \alpha \end{cases} \quad (2)$$

Where,

$$a(x,u,d) \overset{\Delta}{=} \dot{y}(t) - \dot{y}^0(t) = \frac{\partial \bar{h}}{\partial x}(\bar{f}(x,d,\theta) + \bar{g}(x,d,\theta)u(t)) - k_1(\dot{y} - y) - k_0 \int_0^t (\dot{y} - y)dt \quad (3)$$

W is used as the positive weighted matrix, α as limited value of controlled variable, and K1,K2 for the pending diagonal matrix.

3. Self-Adaptation Controls Based On Equivalent Disturbance Signal

3.1 Input Equivalent Disturbance Process

Through Euler discretization on formula (1), nonlinear discrete equation can be obtained shown as the following:

$$\begin{cases} x(k+1) = x(k) + \Delta t f(x(k), \theta(k), d(k)) + \\ \Delta t g(x(k), \theta(k), d(k))u(k) + \Gamma(k)v(k) \\ y(k+1) = h(x(k+1), \theta(k+1), d(k+1) + \\ e(k+1) \end{cases} \quad (4)$$

Here, noise model $\Gamma(k)$ is set as known number, and partial system is observable. Formula (4) is used to describe the model:

$$\begin{cases} x(k+1) = x(k) + \Delta t \bar{f}(x(k), \theta(k), d(k)) + \\ \Delta t \bar{g}(x(k), \theta(k), d(k))u(k) + \Gamma(k)v(k) \\ y(k+1) = \bar{h}(x(k+1), \theta(k+1), d(k+1) + \\ e(k+1) \end{cases} \quad (5)$$

In last formula, this paper uses $\bar{f}, \bar{g}, \bar{h}$ to describe standard model in this system. In formula (5), θ(k)stands for time varying parameter and d(k) for model error which is regarded as uncertainty in discussion. Both of them are integrated into equivalent disturbance $\delta(k) \in R^m$. $x_e(k) = [x^T(k)\delta^T(k)]^T$.

It is set as expanded state vector, plus the state equation $\delta(k+1) = \delta(k)$, and then an approximate equivalent form as follows can be obtained:

$$\begin{cases} x_e(k+1) = \overline{f_e}(x_e(k)) + \overline{g_e}(x_e(k))u(k) + \Gamma_e(k)v(k) \\ y(k+1) = \overline{h_e}(x_e(k+1) + e(k+1)) \end{cases} \tag{6}$$

Where:

$$\overline{f_e}(x_e(k)) = \begin{bmatrix} x(k) + \Delta tf(x(k), \theta(k), d(k) \\ + t\Delta tg(x(k), \theta(k), d(k)\delta(k)) \\ \delta(k) \end{bmatrix}$$

$$\overline{g_e} = (x_e(k)) = \begin{bmatrix} \Delta t\overline{g}(x(k), \theta(k), d(k)) \\ 0 \end{bmatrix}, \Gamma_e(k) = \begin{bmatrix} \Gamma(k) \\ 0 \end{bmatrix} \quad \overline{h_e}(x_e(k+1)) = h(x(k+1))$$

This paper estimates the expanded state $x_e(k) = [x^T(k)\delta^T(k)]^T$ with the help of strong tracking filer (STF) and formula (6). Under the sense of STF, C(k) is set the minimum and intersect with one another. Then, the equivalent disturbance for process (3) will be $\delta(K)$ obtained from above (Fig. 1).

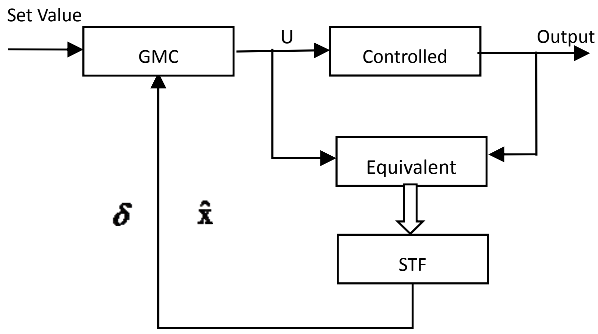


Fig. (1). AGMC System Principle

3.2 Input Equivalent Disturbance Signal Compensation

From what has been discussed above, the whole system errors caused by factors like model errors, time varying parameters and external disturbance will affect its control performance. Therefore, this paper concludes that the input signals compensate the whole system. Obviously, there exists a non-linear relation between the control system error input signals and output values, which is described by formula (7):

$$Q = f(I) \tag{7}$$

In the formula, f stands for the relational function of the non-linear function. It means the effect on the control system exerted by non-linear parameters. This paper intends to compensate it. The input will be output voltage of PID controller, and output value is electric current I of servo control, as follows:

$$I = G(u) \tag{8}$$

The amount of electro-hydraulic control after compensation：

$$Q = f(I) \tag{9}$$

Put formula (8) into formula (9), the following will be achieved：

$$Q = f(G(u)) \tag{10}$$

As f is a monotone function, its inverse function will be：

$$G(u) = f^{-1}(Q) \tag{11}$$

Where, f^{-1} is the inverse function of f . Supposed there is a linear relation between servo control input and output, then：

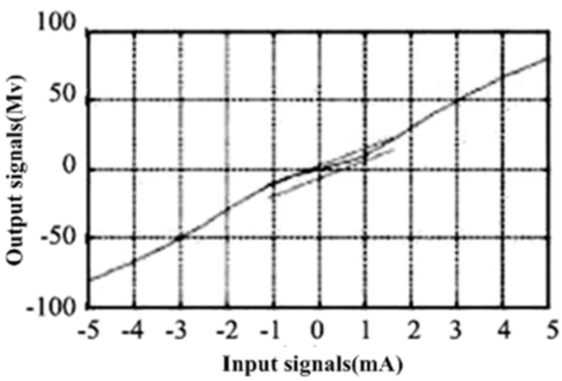
$$Q = K_V I \tag{12}$$

Put formula (12) into formula (11), then formula (13) as follows will be obtained：

$$G(u) = f^{-1}(K_v I) \tag{13}$$

In the last written，the range for I is $[-I_{\max}, I_{\max}]$, $I_{\max}$ among which is the maximum of servo current，adjusted through PD algorithm，the range for output voltage u is $[-U_{\max}, U_{\max}]$. As for the function f , we can obtain it by fitting calculating the curve(Fig. 2).

Fig. (2). Non-linear relations between input and out signals



3.3 To Achieve Self-adaptation Algorithm Generic Model Control (AGMC) by Using Input Equivalent Disturbance

With the help of GMC formula，the formula x(k) in formula (3)can be replaced by the state observed value under STF, and we can optimize OC1 by inputting the solution of equivalent disturbance $\delta(K)$, and set the following as

$$a(\hat{x}_e(k/k),u(k)) = \frac{\partial \bar{y}}{\partial x}[\bar{f}(\hat{x}(k/k)) + \bar{g}(\hat{x}(k/k))(u(k)+\hat{\delta}(k/k))] - k_1(\dot{y}(k) - y(k)) - k_0\int_0^t (\dot{y}(t) - y(t))dt = 0 \tag{14}$$

The expression of AGMC's solution will be：

$$u(k) = [\frac{\partial \bar{h}}{\partial x}[\bar{g}(\hat{x}(k/k))]^{-1}(k_1(y(\dot{y}(k) - y(k)) + k_0\int_0^t (\dot{y}(t) - y(t))dt - \frac{\partial \bar{h}}{\partial x}\bar{f}(\hat{x}(k/k))) - \hat{\delta}(k/k) \tag{15}$$

3.4 Electro-hydraulic Servo Self-adaptation Control System based on AGMC

The structure is uncertain, and time varying parameters and disturbance are unobservable in real electro-hydraulic servo control system[9-12]. This paper will make parameter setting for error factors like model errors, time varying parameters and unpredictable disturbing signals, and input them into system as compensated signals, namely feed forward compensation signals in GMC algorithm. From what has been analyzed above, the electro-hydraulic servo control system algorithm based on input equivalent disturbance has more robustness and strong capability in tracking load. It will be realized as follows(Fig. 3).

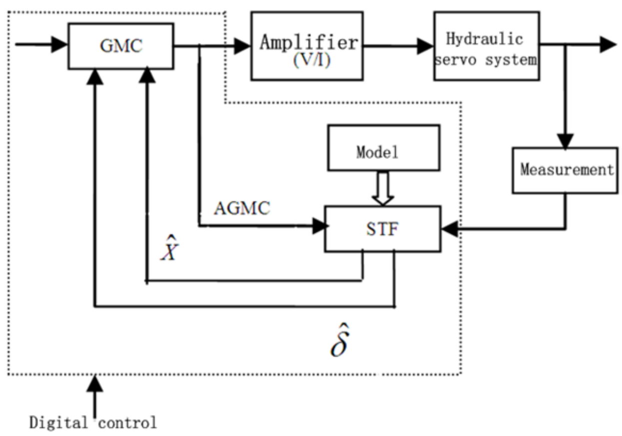


Fig. (3). The Block Diagram of Electro-hydraulic Servo System

the dotted border is generic model unit of input equivalence, which can be achieved through micro-computer and relative digital chips in practice.

4. Stimulation Experiments and Analysis

As is shown in formula (16), this paper will describe the algorithm by making use of the kinetic equation:

$$\begin{cases} A_p \dot{y} + C_t p_L + B_t \dot{p}_L = K_v u \sqrt{p_s - \mathrm{sgn}(u) p_L} \\ A_p p_L = m \ddot{y} + C_p \dot{y} + Ky + F \end{cases} \tag{16}$$

In the formula above, y and m stand for load shift and weight respectively. P_S stands for oil supply pressure, P_L and A_p for pressure coefficient and action area respectively, sgn for sign function, K_V for servo-valve coefficient and F for the disturbing force, C_P for friction between cylinders and pistons, and K for stiffness of cylinders. Generally speaking, leaking is unavoidable in cylinders. Thus, C_t is used to refer to this parameter, and Bt refer to damping ratio.

By fetching a state variable $x = [x_1 \quad x_2 \quad x_3]^T = [y \quad \dot{y} \quad p_L]^T$, the system state equation and output equation can be deduced as follows:

$$\dot{x} = AX + Bu + DF \tag{17}$$

$$y = [0 \quad 0 \quad 1]x \tag{18}$$

where:

$$A = \begin{bmatrix} 0 & 1 & 0 \\ -\dfrac{K}{m} & -\dfrac{Cp}{m} & -\dfrac{Ap}{m} \\ 0 & -\dfrac{A_p}{B_t} & -\dfrac{C_t}{B_t} \end{bmatrix} \quad B = \begin{bmatrix} 0 \\ 0 \\ b(x) \end{bmatrix} \quad D = \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$b(x) = \frac{K_v}{B_t}\sqrt{p_s - \mathrm{sgn}(u)x_3}$$

From the analysis above, we can get its relative order as 1, and it meets the control rate u. b(x) indicates that the system has a strong non-linear, and pL can be calculated according to the measured parameters. Based on Table 1, this paper will stimulate the system through MATLAB, in which y1 and y2 stand for PID control and AGMC control. In the process of stimulating AGMC, the sapling period is set as t=0.005s, K1=1.2 ,K0 =0.8. When tracking filter waves, in view of the error sources, this paper will assign values to process noise covariance matrix Q(k), measurement noise covariance matrix R(k) and B and A attenuators, and they are Q(k)=1.5×10-2、R(k)=0.8×10-2、B=10、A=1. According to the response curve, AGMC responds quickly with little overshoot, and thus is better than PID control. The changes of system equivalent disturbance can be seen (Fig. 5), where when t=0.35, disturbance is added into, which proves AGMC has a strong repair ability.

Table 1. Relative Parameters in System

Items	Value
Load Weight m/kg	150

Damping Ratio Bt	0.08×10-11
Action Area Ap /m2	0.012
Amplification Kv	0.001
Leaking Coefficient Ct	2.6×10-10
Stiffness K	72
Oil Supply Pressure ps/Mpa	12

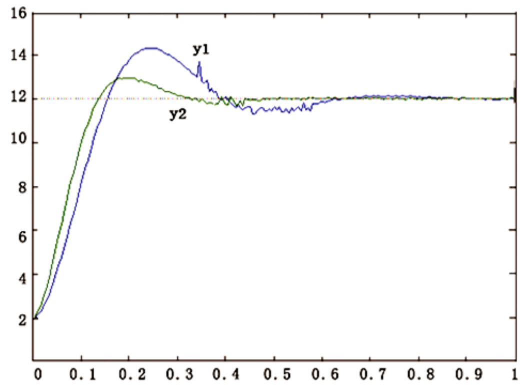


Fig. (4). System Step Response Curve

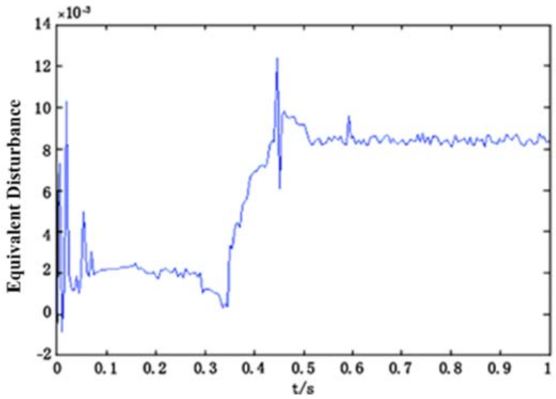


Fig. (5). Input Equivalent Disturbance Curve

5. Conclusions

For the non-linear problems existing in the electro-hydraulic servo control system, especially when the disturbance and parameter change, its control effect is poor. This paper introduces an algorithm of generic model control (AGMC) based on self-adaptation, which can effectively track the time varying parameters and unobservable disturbance, therefore its robustness is greatly improved. The experiments prove that such algorithm has a strong tracking effect and is easy to control and set parameters. Therefore, it has an important value of promotion in the field of industrial production.

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