Dynamic Sliding Mode Control Scheme for Electro-Hydraulic Position Servo System

Rui Tang\textsuperscript{a}, Qi Zhang\textsuperscript{b}\textsuperscript{*}

\textsuperscript{a} School of Electromachinical Engineering, Pan-zhihua University, Jichang Road No.10, Panzhihua617000,China
\textsuperscript{b} School of Manufacturing Science and Engineering,Sichuan Universiyt, No.24 South Section 1, Yihuan Road, Chengdu617000,China

Abstract

In order to solve the uncertainties in the position servo system, caused by servo system without modeling accurately, which may cause the deterioration of the control quality of the electro-hydraulic position servo system (EHPSS) and even lead to its instability, a dynamic sliding mode control strategy is proposed for an EHPSS. Based on dynamic switching function, the proposed control strategy has fast response and good disturbance rejection capability. The numerical simulation is presented to verify the effectiveness of the proposed control scheme. It is shown from the experimental results that the proposed controller offers several advantages such as fast response, good disturbance rejection capability, good position tracking capability and so forth. It is also revealed from simulation results that the proposed control strategy is valid for the EHPSS.

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1. Introduction

EHPSS are widely used in many industrial applications and mobile systems because of their high power-to-weight ratio, high stiffness, fast response, good position capabilities, and so forth [1]. However, the actual servo system has many uncertainties and highly nonlinear characteristics, which results from the flow-pressure relationship, oil leakage, and etc. Furthermore, an electro-hydraulic servo system suffers many kinds of disturbances such as the null shift of a servo valve and load torque variations [2].

Sliding mode control is robust with respect to system uncertainties through the use of switching control [3], but it has disadvantage of chattering. Because of the chattering, the property of servo system will be damaged. In order to overcome the chattering, Papers [3],[4],[5] have introduced two ways to reduce the
chattering (the first way is the boundary layer control, and the second approach is the dynamic sliding mode control DSMC), and it reduce the chattering effectively.

In this respect, a dynamic sliding mode control, based on dynamic switching function, is proposed for an EHPSS to obtain good capacity of position tracking and reduce the chattering in SMC.

2. System Description

2.1. The consistence of the system

The basic function of the EHPSS is to force the output to follow the input order by adapting the proper controlling strategy, which is regulated by the controller. The structure of it is depicted in figure 1 [6].

![Fig. 1. Structure diagram of electro-hydraulic position servo control system](image)

3. Dynamic sliding mode controller

3.1. Design of dynamic sliding mode controller

Consider an SISO nonlinear system:

\[
\begin{cases}
\dot{x}_i = x_{i+1}, \quad i = 1, 2, 3, \ldots, n-1 \\
\dot{x}_n = f(x) + g(x)u + \eta \\
y = x_1 
\end{cases}
\]

In the equation (1), \( y \) is output, \( u \) is the input, \( f(x), g(x) \) are smooth function, \( \eta \) is uncertainty, by the theory of sliding mode control and hydraulic transmission, the error of tracking and sliding surface switching function can be denoted as:

\[
\begin{cases}
e = r - r_d \\
s = c_1e_1 + c_2e_2 + c_3e_3 + \cdots + c_{n-1}e_{n-1} + e_n = \sum_{i=1}^{n-1} c_i e_i + e_n
\end{cases}
\]

In equation (2), the parameters \( c_i \) must satisfy the condition that the following equation can keep Hurwitz stability.

\[
P_{n-1} + c_{n-1}P_{n-2} + c_{n-2}P_{n-3} + \cdots + c_2P_1 + c_1
\]

In the equation (3), \( P \) is laplacian operator, by (1), (2) the sliding surface is written as:

\[
\dot{s} = f(x) + g(x)u + \eta - y_d^{(n)} + \sum_{i=1}^{n-1} c_i e_{i+1}
\]
Next, the novel dynamic switching function can be denoted:
\[ \sigma = \dot{s} + \lambda s \]  \hspace{1cm} (5)
The above equation is a first order system with asymptotically stability, when \( \sigma = 0 \). In order to design and analyse the controller, some assumptions has been made.

**ASSUME 1:** The uncertainty of the system is bounded and the symbol of \( g(x) \) is constant.
\[ |\eta| \leq D(x), \forall x \in \mathbb{R}^n \] \hspace{1cm} (6)

**ASSUME 2:** The derivative of the uncertainty is bounded.
\[ |\dot{\eta}| \leq \overline{D(x)}, \forall x \in \mathbb{R}^n \] \hspace{1cm} (7)

**ASSUME 3:** There exists a positive number \( \varepsilon \), and it satisfies the following equation.
\[ \varepsilon > (c_{n-1} + \lambda)D(x) + \overline{D(x)} \] \hspace{1cm} (8)

According to the lyapunov stability theory, the control law is obtained:
\[ \dot{u} = g^{-1}[-((c_{n-1} + \lambda)g + \dot{g})u - (c_{n-1} + \lambda)f - f + (c_{n-1} + \lambda)r_d^n + r_{d+1}^n \]
\[ - \sum_{i=1}^{n-2} c_i e_{i+2} - \lambda(\sum_{i=1}^{n-1} c_i e_{i+1} + \dot{e}_n) - \varepsilon \text{sgn}(\sigma)] \] \hspace{1cm} (9)

3.2. Stability analysis

**THEOREMS 1:** the designed controller should ensure the existing condition of sliding mode.
**PROOF:** according to the lyapunov stability theory, consider the lyapunov function as:
\[ V = \frac{1}{2} \sigma^2 \] \hspace{1cm} (10)

By (1)(2)(4)(5), the following equation will be obtained based on the above assumptions:
\[ \dot{\sigma} = \sum_{i=1}^{n-2} c_i e_{i+2} + c_{n-1} \dot{e}_n + \ddot{e}_n + \lambda(\sum_{i=1}^{n-1} c_i e_{i+1} + \dot{e}_n) \] \hspace{1cm} (11)

Inserting equations shown in (1) and (2) into (12):
\[ \dot{\sigma} = \sum_{i=1}^{n-2} c_i e_{i+2} + \lambda(\sum_{i=1}^{n-1} c_i e_{i+1} + \dot{e}_n) + (c_{n-1} + \lambda)(f - r_d^n + g u + \eta) + \frac{dg}{dx} \dot{x} \]
\[ - r_{d+1} + \frac{dg}{dx} \dot{x} + g \dot{u} + \dot{\eta} \] \hspace{1cm} (12)

Multiplying \( \sigma \) by (12) and inserting control law shown in (9) into (12) yields:
\[ \sigma \dot{\sigma} = \sigma[(c_{n-1} + \lambda) \eta + \dot{\eta} - \varepsilon \text{sgn}(\sigma)] = [\sigma(c_{n-1} + \lambda) \eta + \sigma \dot{\eta} - \varepsilon |\sigma|] \] \hspace{1cm} (13)

According to the assumptions:
\[ \sigma \dot{\sigma} = [\sigma(c_{n-1} + \lambda) \eta + \sigma \dot{\eta} - \varepsilon |\sigma|] \]
\[ < \sigma(c_{n-1} + \lambda) \eta + \sigma \dot{\eta} - [(c_{n-1} + \lambda)D(x) + \overline{D(x)}] |\sigma| \leq 0 \] \hspace{1cm} (14)

Therefore, stable tracking can be achieved.

4. Numerical simulation

According to the hydraulic technology and the hydraulic servo-control, the open loop transfer function of EHPSS is obtained by corresponding parameters (be omitted)[6-8]:
\[ G(s) = \frac{132.5}{s(s + 26.5)} \]  
(15)

The parameters for simulation are:
\[ \epsilon = (c_{n-1} + \lambda)D(x) + D(x) + 2.0, \quad D(x) = 1.5, \quad D(x) = 1.5, \quad x(0) = [0.5 \quad 0], \quad \lambda = 15, \quad c_i = 5, \]
\[ d(k) = 1.5 \sin(t), \]

The simulation results are shown in Figures from 2 to 5.

Fig. 2. Position tracking of the position servo system

![Fig. 2. Position tracking of the position servo system](image1)

Fig. 3. Position tracking errors of the position servo system

![Fig. 3. Position tracking errors of the position servo system](image2)

Fig. 4. Sliding Surface of DSMC

![Fig. 4. Sliding Surface of DSMC](image3)
Figure 2 shows the dynamic sliding mode control position tracking, and the tracking errors are expressed in figure 3. Figure 4 is the sliding surface of the dynamic sliding mode control position tracking, the derivative of control input is shown in figure 5. The simulation results are analysed and the conclusion is reached that the dynamic sliding mode controller has a good performance on position tracking, and the proposed control strategy is valid for the EHPSS. The problem of chattering was inhibited obviously, and the ability of anti-interference and anti-parameters perturbation, stability and control quality of the system were all improved.

5. Conclusions

In the work reported here, we investigated the feasibility of dynamic sliding mode control for the position control of EHPSS. First, the description of the EHPSS was introduced. Then, the theoretical basis and stability analyses of the proposed control were described in detail. Moreover, simulation and experimentation were carried out to test the effectiveness of the proposed control systems. It is also revealed from simulation results that the main advantages of the adopted nonlinear control design approach applied to the EHPSS are as follows: (1) It has a good performance in position tracking, and the proposed control strategy is valid for the EHPSS. (2) The problem of chattering was inhibited obviously, and the ability of anti-interference and anti-parameters perturbation, stability and control quality of the system were all improved.

References