Fixed Time Fault-Tolerant Control of Electro-hydraulic Servo System based on RFESO

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***Abstract*—A fixed time fault-tolerant control method is proposed for electro-hydraulic servo systems, which can ensure high-precision displacement tracking control of hydraulic cylinders within a fixed time in the presence of unknown nonlinearity, external disturbances, and actuator faults in the system, and the convergence time and performance are independent of the initial state of the system. This article first designs a reduced order fixed time extended state observer RFESO for estimating the lumped uncertainty of electro-hydraulic servo systems. The observer only requires two orders, effectively reducing computational complexity, and the estimation error can achieve fixed time convergence. Secondly, based on the designed RFESO, this paper develops a fixed time fault-tolerant controller for the electro-hydraulic servo system, which does not require any information about the overall uncertainty of the system. Finally, the effectiveness of the proposed method was simulated and verified in the Matlab/Simulink environment, and relevant experimental verifications were conducted on the electro-hydraulic servo system experimental platform.**

***Index Terms*—Electro-hydraulic servo system, fixed-time stable, fault-tolerant control, extended state observer.**

I. Introduction

Electro-hydraulic servo system (EHSS), as a composite control system that combines electrical, control, and hydraulic technologies, has the advantages of high power density, fast response speed, and the ability to provide high torque output. It has been widely used in industrial and automation fields, such as hydraulic robotic arms [1], aerospace [2], engineering vehicles [3], etc. However, the presence of nonlinear friction, model parameter uncertainty, and external disturbances can have a significant impact on the control performance of EHSS. To achieve high-precision control of EHSS under unknown nonlinearity and external disturbances, many scholars have conducted relevant research.

Shen et al. designed a finite time observer to estimate the non matching disturbance of EHSS and used an adaptive rate to handle parameter uncertainty problems; Ba et al. designed two different high-order observers to estimate the lumped uncertainties in EHSS pressure dynamics and force dynamics, respectively; Pan Changzhong et al. used RBF neural networks and corresponding weight adaptation rates to approximate the lumped disturbances composed of unknown disturbances and model uncertainties, and employed a tangent type time-varying obstacle Lyapunov function to solve the output constraint problem of position tracking in electro-hydraulic servo systems. In addition, electro-hydraulic servo systems often operate in harsh environments such as high loads, heavy pollution, strong vibrations, and impacts, which can easily lead to physical component failures, especially actuator failures, which can seriously affect the reliability and safety of the system. Fault tolerance control (FTC) technology is an effective way to handle system failures, mainly divided into passive fault-tolerant control and active fault-tolerant control. Passive fault-tolerant control utilizes the robustness of the controller itself, which can tolerate faults within a certain range without affecting system performance. However, at the beginning of design, possible fault situations must be considered, and the fault-tolerant capability is relatively limited. Active fault-tolerant control is the use of relevant information to readjust the structure or parameters of the controller after a fault occurs, compensate for the impact of the fault in real time, and ensure that the system can still operate stably and meet performance requirements in the event of a fault. This method belongs to active fault-tolerant control. Actuator faults are often divided into loss of effectiveness (LOE) faults and bias faults . For EHSS, actuator LOE faults include servo valve or relief valve faults, hydraulic cylinder faults, and insufficient pump station oil supply pressure; The actuator bias fault is usually caused by internal and external leakage faults due to damage to the sealing system. In recent years, there have been some studies on fault-tolerant control for EHSS, such as Li Haitao et al. , who considered the possible problem of electro-hydraulic servo valve faults in gas turbine electromechanical servo systems and proposed a fault-tolerant control method based on fuzzy PID signal compensation. Phan et al. considered both actuator LOE faults and hydraulic cylinder leakage faults, and designed nominal and reconfigurable controllers using instruction filtering backstepping and nonlinear disturbance observers. Bahrami et al. proposed an adaptive gain hyper twisted sliding mode observer for fault-tolerant control of EHSS, which relaxes the conditions of uncertainty and fault distribution. In addition, the equivalent output error injection characteristic of sliding mode technology is utilized to propose a fault reconstruction strategy. Shen et al. proposed a finite time observer to estimate the fault signal of EHSS and compensate for it, and then used preset performance constraint control to ensure that the tracking error is always within the preset limit range, even in the presence of faults. However, most of the above works have only achieved Uniform Ultimately Bound (UUB) control or finite time control of the system. The convergence time and performance of these control methods are affected by the initial state of the system, which is an undeniable problem for systems with unknown initial states. To this end, Polyakov proposed a fixed time control method that ensures the system converges to the equilibrium point within a fixed time limit and is not affected by the initial state. Inspired by the above work and existing problems, this paper proposes a fixed time fault-tolerant control method for electro-hydraulic servo systems, with the main contributions as follows:

(1) This article proposes a Reduced order fixed time extended state observer (RFESO) to estimate the aggregate uncertainty caused by unknown nonlinearities, external disturbances, and actuator failures in EHSS, and the estimation error can achieve fixed time convergence.

(2) Based on the designed RFESO, this paper develops a fixed time fault-tolerant controller for EHSS, which ensures high-precision displacement tracking control of the hydraulic cylinder within a fixed time without being affected by the initial state of the system, even in the presence of the problem mentioned in contribution (1).

(3) The method proposed in this article does not require any prior information about the aggregated uncertainty of EHSS, and its effectiveness has been verified through simulation and experiments on an electro-hydraulic servo system platform.

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