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Application of self-tuning fuzzy PID controller for a SRM direct drive volume control hydraulic press

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ABSTRACT

A new kind of volume control servo hydraulic press driven directly by Switched Reluctance Motor (SRM) is presented in this paper. In considering the saturation and dead zone nonlinearity as well as the time-variability and the time lag existed in SRM direct drive volume control system, a fuzzy PID control method is introduced to improve the overall performance of the electro-hydraulic position servo system. The relationships between the PID parameters and the response characteristics of electro-hydraulic position servo system are investigated. The fuzzy inference rules which enable adaptive adjustment of PID parameters are established based on the error and change in error. The simulations and experiments of step response and cosine tracking are carried out on the SRM direct drive hydraulic press. The results indicate that the fuzzy self-tuning PID method has great ability of restraining external disturbance, and it can effectively raise the position tracking ability of the volume control electro-hydraulic servo system.

1. Introduction

Hydraulic press is widely used in machinery manufacture fields such as hydraulic punching, pressing and bending machines, and molding technology because of its high power/mass ratio, fast response, high stiffness and high load capability. However, the conventional hydraulic press adopting the valve-controlled hydraulic system has had such drawbacks as complex structure, much energy consumption, plentiful heat generation, high noise, serious vibration, high precision requirement of oil filtrating and throttle losses at the control valves.

With the gradual maturity of motor speed governing and servo control techniques, the volume control electro-hydraulic servo systems driven directly by various kinds of servo motors have emerged in recent years, which overcome the disadvantages of valve-controlled system radically. Many researches have proved that the volume control system without valves has the properties of more compact structure, better reliability, and higher mechanic efficiency. Furthermore, the closed volume control loop driven by servo motor directly possess a series of advantages such as wide speed governing range, high control accuracy, good performance of energy saving, and easy realization distribution intelligent control with wire to transfer power instead of steel tube (Bosch, 1995; Glauss, 2000; Ito, Sato, & Maeda, 1997; Kazuo & Yutaka, 1988; Sato, 2001). Since Sprockhoff introduced the pump-controlled motor loop into the control of hydraulic cylinder and studied the dynamic behavior of pump-controlled symmetrical cylinder in 1979, many kinds of closed volume control loops are put forward to solve the balance of volume flow and to improve the response frequency of the volume control system. The performances similar to valve-controlled system are obtained. The volume control electro-hydraulic systems have been used in plastic injection moulding machine, aircraft actuation system and mobile machinery (Bosch, 1995; Glauss, 2000). This technique has also caused the extensive attentions in Japan owing to its energy saving characteristic. The direct drive volume control hybrid servo pump has been developed, and applied in CNC pipe bending machines and hydraulic servo control of steering system for ship successfully (Ito et al., 1997; Kazuo & Yutaka, 1988; Sato, 2001). In China, much research work has been done on the properties and efficiency of valveless electro-hydraulic servo system (Lin, Duan, & Bi, 2007; Quan, Li, & Wang, 2006; Wang, Wang, & Wang, 2007). It can be seen that the valveless volume control system is an ideal approach to overcome the disadvantages of traditional valve-controlled hydraulic systems. Thus, it has been improved and applied rapidly in the past 20 years.

In this paper, the volume control technique is introduced into the field of hydraulic press servo control to reduce energy consumption. A kind of novel volume control hydraulic press driven directly by SRM is developed to substitute the SRM direct drive volume control system for the primary valve-controlled

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system. However, the SRM direct drive volume control electro-hydraulic servo system similar to other hydraulic systems is inherent in having many uncertain, time-variant and highly nonlinear characteristics due to the flow–pressure relationship, oil leakage, dead zone of SRM, volume flow unbalance of asymmetrical cylinder, etc. Consequently, the conventional control approaches based on a linear model may not guarantee satisfactory control performance for the SRM direct drive volume control position servo systems.

In order to solve the electro-hydraulic servo control problems, some research efforts on adaptive control approaches were made. One of the intelligent control methods is fuzzy control which imitates the logical thinking of humans and is independent from accurate mathematical model of the controlled object. Accordingly, the fuzzy control has extensively been implemented in electro-hydraulic servo control for overcoming some shortcomings of the traditional PID. An adaptive fuzzy controller was used to control two processes of upsetting and thixoforging for a hydraulic forging machine (Lee & Kopp, 2001). A new fuzzy controller using the phase plane was proposed for an electro-hydraulic fin servo system of a missile (Sang & Hyung, 2003). The hydraulic punch trajectory was assured by a fuzzy logic controller that was proved to have a good relation between performance and difficulty to implement and tune (Ferreira, Sun, & Gr'acio, 2006). A two-degree-of-freedom fuzzy controller, consisting of a one-step-ahead fuzzy prefilter in the feed-forward loop and a PI-like fuzzy controller in the feedback loop, has been proposed for foot trajectory tracking control of a hydraulically actuated hexapod robot (Ranjit & Kenzo, 2007). An integrated fuzzy controller comprising of a feed forward controller and a fuzzy tracking controller was proposed to achieve a synchronous positioning objective for a dual-cylinder electro-hydraulic lifting system (Chen, Liu, Cheng, & Chiu, 2008). However, the design of fuzzy rules depends largely on the experience of experts or input–output data. There is no systematic method to design and examine the number of rules, input space partitions and membership functions. The control precision is usually not ideal because the fuzzy control is a nonlinear method and the output of the controller has a static error. For these reasons, the fuzzy PID control which combines the traditional PID control and the fuzzy control algorithm has proved to be a good solution. In order to improve pressure control and to adapt it to the variations, a self-adjusting hybrid fuzzy PD controller was used to meliorate the dynamic and static behavior in the control of variable displacement pumps. The pressure control experience indicates that self-adjusting fuzzy PD controllers could effectively be applied to hydraulic systems with variable loads (Lovrec & Faber, 2006). A self-adaptive fuzzy PID which can adjust PID parameters on-line was designed for the direct drive electro-hydraulic servo system. The simulation results show that the fuzzy PID controller can obtain good dynamic performance and is robust to the external disturbances (Lin et al., 2007; Wang et al., 2007). Ahn and Kha (2008) presented a PID controller tuning by genetic algorithm and fuzzy logics for shape memory alloy actuators.

In this paper, a self-tuning fuzzy PID controller which can adaptively adjust controller parameters on-line is designed to solve the position servo control of SRM direct drive volume control hydraulic press. The fuzzy inference rule is established based on the relationships between the PID parameters and response characteristics of hydraulic press. The simulations and experiments have been done to prove that the method is effective in improving the dynamic property and decreasing the steady-state error of volume control electro-hydraulic position servo system.

2. Working principle of SRM direct drive volume control hydraulic press

The working principle of the volume control hydraulic press is illustrated in Fig. 1. The flow pressure, volume and direction of working medium can be controlled by using a SRM to drive the bi-directional axial piston pump directly. Hence the movement speed, position and direction of hydraulic press slider are controlled by pump without valve. The total system consists of SRM speed control module, volume control module, micro computer control module and auxiliary hydraulic loop module.

The SRM speed control module, including SRM and its servo driver, controls the turning speed, angle, direction and torque of pump. The volume control module is made up of a bi-directionally dischargeable pump and an asymmetric piston cylinder, and controls the movement velocity, position, pressure and direction of piston by changing the turning speed and direction of pump. The micro computer control module, which includes micro computer, A/D D/A card and position sensor, can accomplish data sampling, processing and control operation. The auxiliary hydraulic loop module is composed of two relief valves and two check valves connected with oil tank and the oil pipes of main loop. The relief valves play a role of unloading when overload and the check ones solve the unbalance of volume flow between the rod-side and piston-side. When the piston moves downwards, the pump delivers the hydraulic oil towards piston head but with less

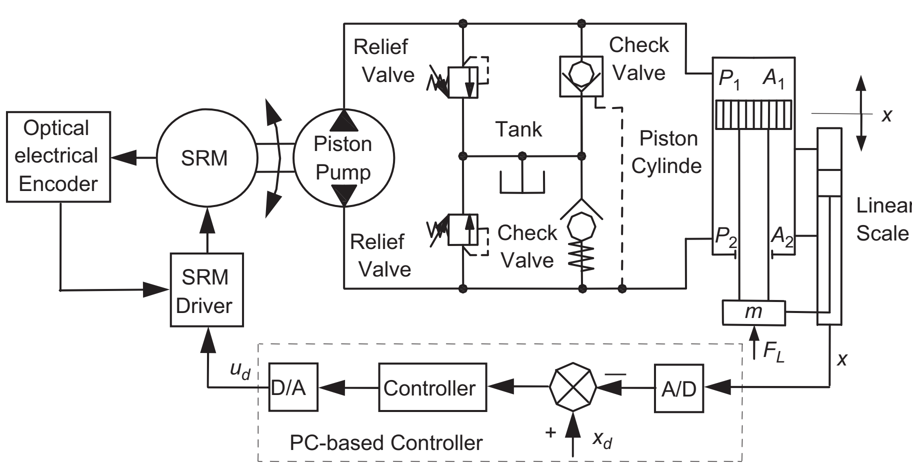

Fig. 1. Schematic diagram of the SRM direct-drive volume control hydraulic press.