Research on Synchronous Control Technology of Hydraulic Motor based on Constant Power Speed Control Circuit

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Abstract

This article introduces the research on synchronous control technology of hydraulic motors using constant power speed control circuits. It discusses the development history of hydraulic transmission systems, with a focus on systems that maintain constant output power while adjusting motor speed. This study emphasizes the importance of this control method for applications such as engineering machinery that require stable power and precise speed regulation under complex working conditions. Control the hydraulic system through a PID controller to synchronize the speeds of the two motors.

Keywords

Hydraulic Transmission; Constant Power Speed Control; Volumetric Speed Control Circuit; Synchronous Control; Hydraulic Motor; Actuator; Industrial Application; PID Control; Load Sensitive Valve; Simulation Modeling; Energy Efficiency.

1. Introduction

Hydraulic transmission originated during the Industrial Revolution, initially applied to simple presses. The invention of hydraulic cylinders and variable-displacement pumps in the early 20th century laid the foundation for hydraulic speed regulation systems[1]. Fixed Pump-Variable Motor Systems: Adjusted motor displacement to achieve constant power, but with limited speed ratios .Variable Pump-Fixed Motor Systems: Improved low-speed stability by regulating pump flow, though efficiency lagged behind fixed-pump systems.

Hybrid Systems: Combined variable pumps and motors, achieving speed ratios over , but required strict control sequences.

Research on synchronous control technology of hydraulic motor based on constant power speed control circuit[2]. Constant power speed control circuit is a system used for motor control, aiming to maintain constant output power while adjusting the output of the motor. In general, it is a quantitative pump variable motor type volumetric speed control circuit[3]. This control method is very important in applications that require precise speed regulation and stable output power, such as in elevators, cranes, and some industrial equipment.

The working principle of the volumetric speed control circuit is to adjust the movement speed of the actuator by changing the displacement of the variable pump or variable motor in the circuit. In this circuit, the oil output by the hydraulic pump directly enters the actuator without overflow loss or throttling loss, and the working pressure changes with the load, resulting in high efficiency and less heat generation.

With the rapid progress and development of industry, the application fields of these heavy industrial machinery are becoming increasingly wide[4]. These heavy machinery are important tools for China's large-scale infrastructure construction, and harsh working environments are the norm. The higher their independence, the easier it is to repair and replace parts, and the less susceptible their working condition is to environmental influences, which is an important selection factor[5]. Therefore, hydraulic driven heavy machinery is still the mainstream driving method.

In the process of shield tunneling, due to the joint drive of multiple hydraulic motors by the cutterhead, uneven load distribution may occur when encountering complex working conditions, which can easily cause the safety shaft to break, affecting construction efficiency and posing significant safety hazards. Therefore, high precision is required for the synchronous control of hydraulic motors. A large number of scholars have conducted relevant research on control algorithms and strategies, and Li Chao has studied the application of hydraulic synchronous control circuits in coal mining machinery control; Tan Dun et al. studied the synchronous control strategy of dual hydraulic motors based on improved particle swarm optimization algorithm, and achieved good control effects.

2. Basic Principles of the System

2.1 System Working Principle

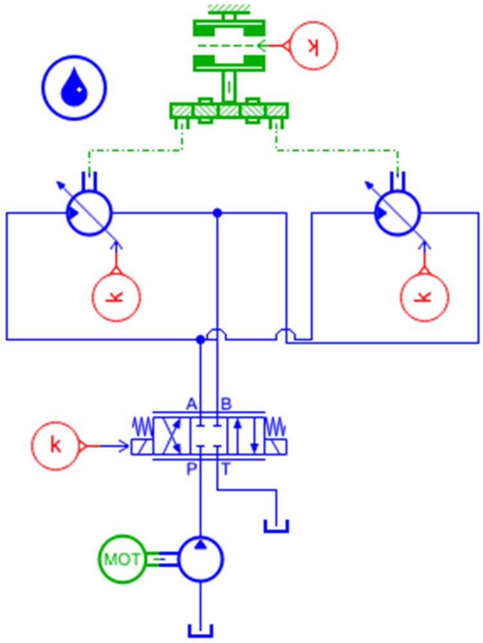

Figure 1. Hydraulic schematic diagram

The working process of the hydraulic synchronization system is as follows: the electric motor drives the quantitative pump to rotate, and outputs a certain amount of pressure oil into the main circuit. The electro-hydraulic reversing valve controls the rotation of the motor, and the low-pressure oil at the outlet of the motor flows back to the oil tank through the reversing valve.

2.2 Calculation and Selection of Main Components for Hydraulic System

Set the maximum driving torque T_d of the cutterhead, and the output torque of each motor:

$$T_{m1} = \frac{T_d}{Z_m i_c i_j \eta_j} \tag{1}$$

Maximum output speed of a single hydraulic motor:

$$n_{max} = n_d i_c i_j \tag{2}$$

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Theoretical speed of hydraulic motor:

$$n_0 = \frac{n_{max}}{\eta_{mv}} \tag{3}$$

The actual maximum flow rate of two hydraulic motors working simultaneously:

$$Q_m = \frac{Z_m n_{max} V_m}{1000\eta_{mv}} \tag{4}$$

Maximum displacement required for the pump:

$$V_P = \frac{Q_m}{n_p \eta_{pv}} \tag{5}$$

Z_m - Number of motors

η_j - Total mechanical efficiency of gear and reducer

In summary, both the hydraulic pump and hydraulic motor are products from Rexroth, with the hydraulic motor having a displacement of 300-500ml/min and the hydraulic pump having a displacement of 300ml/min.

3. System Modeling and Joint Simulation

3.1 System Model

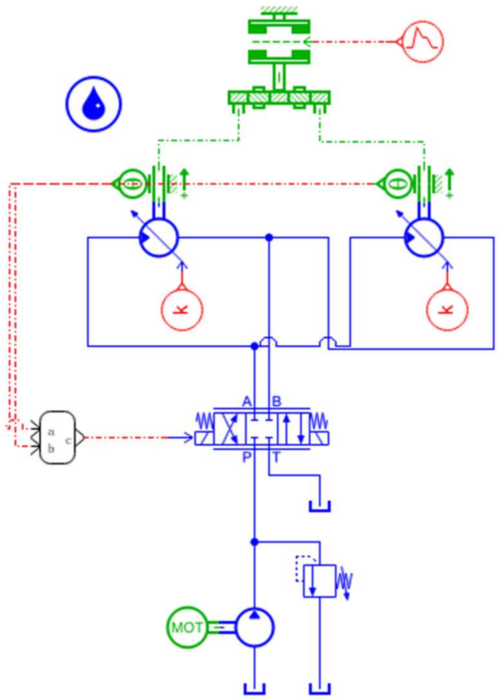

Figure 2. Hydraulic System Simulation Model

Establish an external load model on the hydraulic motor to simulate load fluctuations and measure the response and synchronization error of the hydraulic motor. The speed sensor is responsible for measuring the real-time speed of the motor. When the speed of the dual motors exceeds the

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synchronization accuracy error range, the controller makes corresponding decisions through clustering and calculation, and feeds back the output signal to their respective electro-hydraulic proportional valves. By modulating the opening size of the throttle valve, that is, changing its flow cross-sectional area, the input flow to the motor is controlled, thereby achieving high-precision synchronization of the dual motors. The variable motor serves as the system's executive component, and its rotation is jointly controlled by a pump and a proportional valve.

3.2 Joint Simulation Settings

The interface settings for the joint simulation of AMESim and Simulink are shown in the following figure.

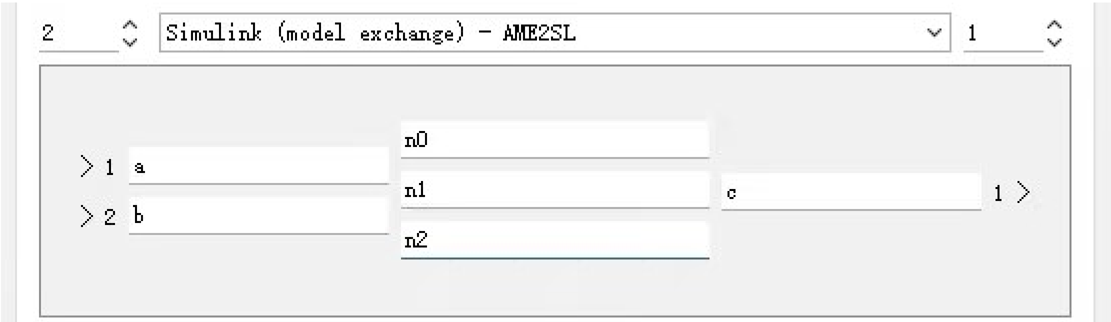

Figure 3. Joint simulation interface

3.3 Controller Design

PID control is a type of linear control, namely proportional integral derivative control. PIDcontrol mainly consists of two parts: the PID controller and the controlled object.

Given the given value r (t), actual output value f (t), and control deviation e (t) of the PID control system, it can be expressed as:

$$\mathrm{e(t) = r(t) - f(t)} \tag{6}$$

To achieve control over the controlled object, the proportional (P), differential (D), and integral (I) terms of the deviation are combined into a control variable using a certain linear method, which is called a PID controller. Its control law can be expressed mathematically as:

$$\mathrm{u(t)} = K_p[e(t) + \frac{1}{T_1}\int_0^t e(t)dt + \frac{T_D de(t)}{dt}] \tag{7}$$

In the formula: u (t) - t moment output control quantity

K_p- scale factor

T_1- integral time constant

T_D- derivative time constant

Convert to transfer function form as:

$$\mathrm{G(s)} = \frac{U(s)}{E(s)} = K_p(1 + \frac{1}{T_1 s} + T_D s) \tag{8}$$

Encapsulate the controller as shown in the following figure.

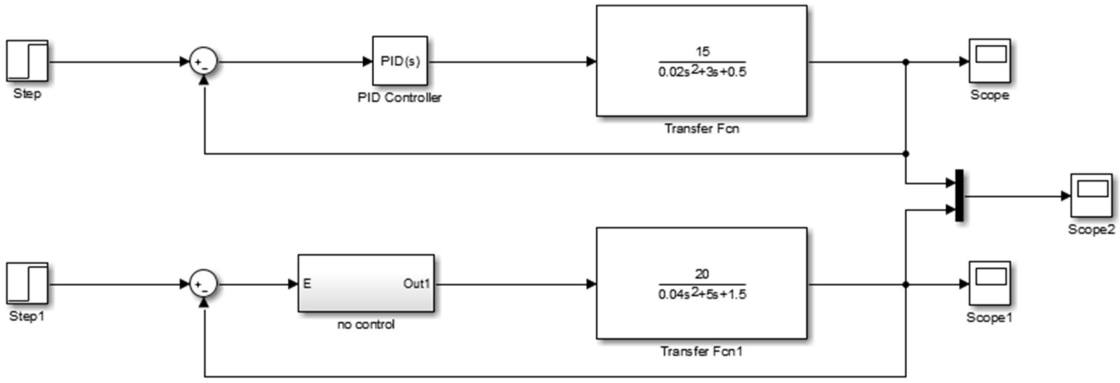

Figure 4. Controller Packaging

4. Conclusion

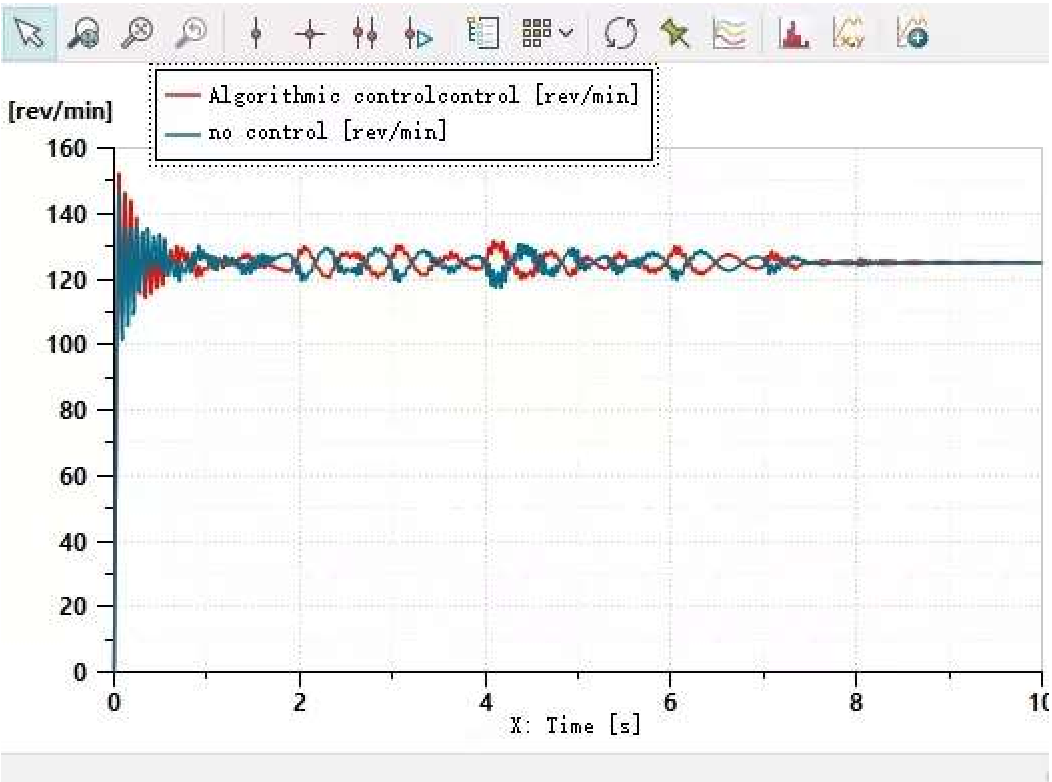

Figure 5. Result Chart

Under PID control, the speed synchronization speed of the hydraulic motor is faster and the overshoot is smaller. Through the coordinated control of variable pump and load sensitive valve, the hydraulic system maintains power stability under variable load conditions.

In the future, the synchronous control technology of hydraulic motors based on constant power speed regulation circuits has a closed and efficient development prospect, and will play an important role in multiple fields. With the continuous advancement of intelligent manufacturing, automation control, and energy-saving technologies, there is an urgent demand for synchronous control of hydraulic systems with asynchronous, high response speed, and high stability. In response to the shortcomings of existing synchronous control schemes in load asynchrony, synchronous regulation, and energy consumption, future research will focus on optimizing control strategies, improving system response speed, and enhancing anti-interference capabilities. The introduction of intelligent control algorithms, such as fuzzy control, neural networks, genetic algorithms, and deep reinforcement learning, will further enhance the system's adaptive capabilities, enabling hydraulic motors to achieve more accurate synchronous control under complex operating conditions. In addition, the application of multi-sensor fusion technology, such as pressure, flow, load detection, and harmonious processing of load detection, will be beneficial for building more accurate feedback control systems and improving the adaptive ability of hydraulic motors under different working conditions.

Under the trend of energy conservation, the optimization of constant power speed regulation circuits will also become a research focus. By combining dynamic power allocation, adaptive flow regulation, and energy recovery technology, energy loss can be reduced and the overall energy efficiency of the system can be improved. At the same time, the rise of electro-hydraulic hybrid drive technology will also promote the development of synchronous control of hydraulic motors. By combining the auxiliary speed regulation capability of motors with the large signal output characteristics of hydraulic systems, more automation can be achieved. In addition, the combination of digitalization and Internet of Things technology will enable hydraulic systems to achieve remote monitoring, self diagnosis, and intelligent optimization control, improving equipment stability and continuity. In the fields of engineering machinery, ship propulsion systems, wind power equipment, and manufacturing, the application of hydraulic motor synchronous control technology based on constant power speed control circuits will be more widespread, promoting the entire industry to develop towards intelligence, automation, and green development

Intelligent Upgrades:Integration of digital twins and IoT for real-time system health monitoring 24.Energy Efficiency Optimization:Development of low-friction materials and adaptive seals to minimize internal leakage (targeting >90% efficiency)[6].Green Technologies:Adoption of biodegradable hydraulic oils and energy recovery devices (e.g., accumulator-based regenerative braking), aiming to cut carbon emissions by 20–30%[7].

This evolution reflects the transition of hydraulic systems from basic mechanical control to intelligent, high-efficiency solutions, driven by interdisciplinary advancements.

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