Optimization of Automatic Control for Water Level in Hydraulic Model Dependent on PMSM Fuzzy Logic Algorithm

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Abstract. Traditional water level measurement requires massive human and material resources. Subject to terrain, weather, and other objective factors, it is often not timely and accurate enough and prone to various disasters. Given this situation, this paper attempts to explore the water level control elements in the model based on the PMSM fuzzy logic algorithm, discuss the optimal control for water level according to the features of water level changes, and adjust the opening degree of the tailgate automatically based on the deviation of given water level from the measured value. The practice demonstrates that the proposed algorithm can optimize the control of water level and improve the precision of automatic control.

Keywords: Hydraulic Model, Water Level, Automatic Control, Optimization Algorithm

Introduction
With the continuous development of social economy in China, science and technology have been applied in various fields constantly. Water conservancy is one of the first fields transformed by information technology [1-3]. Traditional water level measurement requires massive human and material resources and is subject to various objective factors such as terrain and weather. It is often not timely or accurate and prone to various disasters [4-5]. The introduction of automatic control technology in the water conservancy industry has implemented the automatic collection of flow velocity and water level and the automatic control of flow and water level [6]. However, the factors that affect the precision of water level control are directly related to the quality of the model experiment. For example, the traditional PID algorithm is prone to overshoot and cannot obtain the precision as required. To address this problem, this paper attempts to explore the model water level control elements based on the PMSM fuzzy logic algorithm to ensure the optimization precision of the water level automatic control of the hydraulic model more effectively.

1. Mathematical Model and Control Principle of PMSM
In the hydraulic model test, the water level of the model can be controlled by adjusting the opening degree of the tailgate (microcomputer collects the actual water level of the model in real-time through
the water level meter and compares it with the given water level to obtain the deviation and direction. Based on the appropriate control algorithm, the control value is calculated. The control voltage signal after D/A conversion is output and sent to the DC servo controller to control the steering and speed of the DC motor, change the opening of the tailgate, and adjust the model water level (by detecting the water level deviation value constantly, correcting the magnitude and direction of the control voltage so that the model water level can approach the given water level, and implementing automatic computer control of the water level as required in the test). The given water level can be constant or variable. The computer can simulate a constant flow or non-constant flow level process accurately.

The block diagram of the water level control system is shown in Figure 1.

![Figure 1. Block diagram of the control system](image)

For permanent magnet synchronous motors, the rotor magnetic flux position is the same as the rotor mechanical position. Thus, the rotor magnetic flux position of the motor can be obtained by detecting the actual position of the rotor so that the vector control of the permanent magnet synchronous motor is dramatically simplified than that of the asynchronous motor. To implement the linearization and to decouple control of the electromagnetic torque equation, a control method where the stator current vector is located on the q-axis and has no d-axis component is generally applied, that is, \( i_d = i_s, i_q = 0 \), and the stator current is all used to generate torque. The dynamic mathematical model of permanent magnet synchronous motor is shown as follows:

\[
\frac{d}{dt} i_q = \frac{1}{L_q} \left( v_q - R i_q - P \omega r \psi_f \right) \tag{1}
\]

\[
\frac{d}{dt} \omega_r = \frac{1}{J_m} \left( T_e - T_L - B_m \omega_r \right) \tag{2}
\]

\[
T_e = \frac{3}{2} P \psi_f i_q = \frac{3}{2} P \psi_f i_s \tag{3}
\]

Equation (3) shows that the torque of the turbine can be completely controlled by controlling the flow \( i_q \) of the q-axis. After the values of \( i_q \) and \( i_d \) are determined, the inverse transformation of d and q can be performed to obtain the given values \( i_a, i_b, i_c \) applicable to the stator three-phase armature winding current, as long as the amplitude and frequency of the current of the stator is controlled in the inverter, satisfactory torque control features can be obtained.

Current control is the foundation of motor torque control. The purpose of current control is to make the three-phase stator turbulence strictly follow the sinusoidal current given signal. PMSM is a permanent magnet motor based on sine wave back electromotive force. To obtain a stable torque, the stator current shall be mutually balanced and a sine function of the rotor electrical angular displacement. The stator currents shall be balanced with each other. Current hysteresis control in the voltage source inverter has provided a method to control the transient current output for the current hysteresis control of the sine function of the rotor electrical angular displacement in the voltage source inverter. The basic idea is to compare the given signal of the current with the detected actual output current signal of the inverter. If the actual current is greater than the given one, the inverter is changed
The speed control loop is also an essential link in the position servo system. Its control performance is an integral part of the servo performance, which requires a wide speed range, slight speed pulsation, high precision, and fast response. PI controller has been extensively used due to its simplicity, easy implementation, and sound control features. The input of the PI controller is the speed error map, and the output is the given value of torque $T^*$ (which can be denoted as $i^*_{d}$). With Laplace change, the speed PI regulator can be described as follows

$$T^*(s) = \left( K_{ps} + \frac{K_{ps}}{s} \right) \Delta \omega_i(s) \quad (4)$$

Where $\Delta \omega_i$-the error between the actual speed and the given value
$K_{ps}$-scale factor
$k_i$-integral coefficient

In recent years, the application of intelligent control in high-performance permanent magnet synchronous motor drive systems has attracted attention. It is mainly characterized by no complex mathematical modeling, which is especially suitable for motor drive control systems with nonlinearity and mathematical model uncertainty. Based on the principle of fuzzy logic control, a fuzzy controller is established and used in the position servo control system of permanent magnet synchronous motors.

The position error and the rate of change of position error are input as fuzzy variables. The output of the fuzzy controller is the given value of rotational angular velocity. The fuzzy function relationship can be described as the following equation:

$$\omega^*_j(n) = \int_{\text{discrete}} \Delta \omega^*_i(n) = f \left( \Delta e(n), \Delta \theta_i(n) \right) \quad (5)$$

With an appropriate angular velocity given value $\omega^*_j(n)$, the control system can track the given position quickly and accurately according to different operating requirements. The selection of parameters $k_{e}, k_{i}$ should limit the position error and its rate of change within $\pm1$.

To obtain an accurate control amount, the fuzzy method shall express the calculation result of the output membership function. The de-fuzzification method used in the paper is the center of gravity method as follows:

$$i = \frac{\sum_{i=1}^{N} i \mu_{c(k)}(i)}{\sum_{i=1}^{N} \mu_{c(k)}(i)} \quad (6)$$

Where $k$-total number of fuzzy rules
$\mu_{c(k)}(i)$-output membership function corresponding to the k-th rule. The center of gravity method takes the center of gravity of the area enclosed by the membership function curve and the abscissa as the final output value of fuzzy inference to obtain more accurate control.

2. Optimization of Automatic Control for Water Level Based On Hydraulic Model
In the water level process control, PID control algorithm is often used. Given that the action of the tailgate is characterized by keeping the historical position and many advantages of the incremental algorithm, the incremental PID control algorithm is selected as follows.
\[ \Delta U_i = K \left[ e_i - e_{i-1} + \frac{T_i}{T} e_i + \frac{T_i}{T} (e_i - 2e_{i-1} + e_{i-2}) \right] \]  

(7)

Where \( \Delta U_i \) —— increment of the control quantity at the i-th moment; \( K \) —— proportional coefficient; \( T \) —— sampling period; \( T_i \) —— integration time; \( T_d \) —— differential time; \( e \) —— deviation at the i-th moment; \( e_{i-1} \) —— deviation at time i-1; \( e_{i-2} \) —— deviation at time i-2.

In the PID control, when the incremental form (ie output \( \Delta U_i \)) is adopted, the general proportional term and differential term are relatively large. If it is out of control, since the actuator cannot reach the specified action speed of the computer output within a sampling period, the control information can be lost. As a result, the dynamic quality of the system deteriorates, and the transition process is extended. Hence, the PID algorithm can be further improved in the actual control. The control algorithm can be modified in software to address the above problems.

2.1. Output Range Limitation
To prevent the saturation of the servo controller, the control output range is limited to
\[ U_{\text{min}} \leq U_i \leq U_{\text{max}} \]

2.2. Improvement of Proportional Terms
Based on the PID increment algorithm, the proportional coefficient \( K \) has the most significant effect in PID control. The incorrect value of the proportional coefficient will affect the static and dynamic features of the control system. When the proportional coefficient \( K \) is excessively large, although the dynamic response is fast, the overshoot phenomenon can lead to an unstable system; when the proportional coefficient \( K \) is excessively small, it often leads to the result that the system response speed cannot keep up. In the hydraulic model test, especially under non-constant flow conditions, the water level control process is to follow the set water level curve. The curvature of the water level process curve is changed dynamically. To track the water level change process more effectively, a fuzzy control method is added to the control software to imitate the fuzzy reasoning process of the human brain to determine the reasoning rules and make fuzzy decisions dynamically.

2.3. Improvement of Differential Term and Suppression of Interference Signals
The PID control algorithm implements control based on deviation calculation. If the interference signal increases the deviation \( e_i \), the interference signal will have a more significant impact on the adjustment. For the spike interference, removing the coarse value and averaging is used in the control program. Moreover, the differential term is modified separately to suppress the effect of interference. Here, when the point center difference method is used, it does not directly apply the deviation \( e_i \) of the current moment but the mean of the deviations in the past and current 4 sampling times as the benchmark
\[ \bar{e}_i = (e_i + e_{i-1} + e_{i-2} + e_{i-3})/4 \]  

(8)

The differential term is approximately established by the weighted summation form, namely
\[ \frac{T_d \Delta e_i}{T} = \]  

\[ \frac{T_d}{4} \left( \frac{e_i - \bar{e}_i}{1.5T} + \frac{e_{i-1} - \bar{e}_i}{0.5T} + \frac{e_{i-2} - \bar{e}_i}{0.5T} + \frac{e_{i-3} - \bar{e}_i}{1.5T} \right) \]  

(9)

After consolidation, the following can be obtained
\[ \frac{T \Delta e_i}{T} = \frac{T_d}{6T} (e_{i-1} + e_{i-2} - e_{i-3}) \]  

(10)

2.4. Selection of PID Regulator Parameters

To eliminate the oscillation and improve the control effect and precision, after repeated comparisons, a new type of differential tailgate was designed. That is, the flap door with a rectangular door slot was changed to the flap door with a triangular door slot. The width and height were calculated hydraulically. When there was overflow in the door groove, the door top had no water. The differential tailgate has the following advantages:

① The minimum water depth of the triangular overflow trough is 3.0cm at the minimum flow of the model, that is, the minimum water head of the triangular weir. Hence, the whole test process will have no sudden change of the door top from the submerged state to the non-submerged state. The water level fluctuates sharply.

② The triangular overflow groove overflows instead of the door top overflow. The door panel changes from the horizontal state to the almost upright state. The water depth of the door groove is much greater than that of the door top when it is horizontal. Hence, during the adjustment process, the water depth changes slightly. The adjustment of minor and continuous changes can improve the precision of water level control. The actual application of Linhuaigang indicates that the maximum control error prototype is ±2cm, and the model is ±0.2mm.

③ The advantages of the entire width of the flap door and the water leakage of the door gap are guaranteed. The complete automation of tailwater control is effectively implemented.

In the real-time process control of water level, it is required that the control process should be stable, the change of the given value can be tracked quickly, and the overshoot is minimal. With different disturbances, the system output can be maintained at a given value, and the control variable should not be excessively large. The system remains stable. It is challenging to meet the above requirements simultaneously. However, the main requirements shall be met while considering the general requirements. The parameters are generally determined by experiments and can also be obtained by trial or experimental equation. The author sets a parameter in the software so that the PID parameters can be adjusted at any time and dynamically to understand the effect of the parameters on the control effect, which makes the setting and adjustment of PID parameters more intuitive and convenient.

3. Application

When the instrument is working, the vibrating needle in the vibrating head vibrates up and down at 10–50 Hz. When the vibrating needle contacts the water surface, the signal processing circuit obtains a high-level signal; when the vibrating needle leaves the water surface, the signal processing circuit receives a low-level signal. Thus, when the needle is vibrating up and down on the water surface, the signal processing circuit obtains a pulse signal at a duty cycle of 50% that changes in high and low levels.

When the water level changes, the duty cycle of the pulse signal input to the signal processing circuit will change accordingly. If the water level rises, the high-level time is long, and the low-level one is short (there may not even be a low level). The duty cycle is more than 50%.

When the motor drives the screw rod to rotate, the photoelectric rotary encoder connected to the screw rod rotates accordingly. After shaping and phase discrimination, the two sets of pulses generated by the A and B pulses are identified and counted based on the microcontroller system. The probe position is calculated and output for display. Since the photoelectric rotary encoder is a non-contact type, it has a relatively long service life than the traditional absolute encoding code disc, with no code skipping and a much simpler mechanical structure.
With the improved optimization control algorithm, the real-time precision of constant flow control is better than ±0.4mm; the measured control curve of unsteady flow essential coincides with the given one, with a precision better than ±0.8mm.

4. Conclusions
This paper attempts to explore the water level control elements in the model based on the PMSM fuzzy logic algorithm, discuss the optimal control for water level according to the features of water level changes, and adjust the opening degree of the tailgate automatically based on the deviation of given water level from the measured value, to further improve the static and dynamic quality of water level process control.

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