Research on Grab Flat Digging Control Method Based on Fuzzy PID Control

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Abstract. Grab is a common tool in the transportation industry. Traditional grabs have shortcomings such as low automation, limited mining precision, and low operational efficiency. The improvement of automation and intelligence level is an urgent demand in the current market. Grab control system usually adopts AC asynchronous motor as the execution component. Due to its nonlinearity and strong coupling, the existing single closed-loop control method is difficult to achieve the dynamic requirement of position tracking. In order to further improve the accuracy and robustness of the grab position control, a new intelligent control method is proposed. This method adds a position closed loop to the existing AC speed control system to form a triple control system including current, speed and position loop, which could realize real-time adjustment of the position loop parameters through fuzzy PID control. The simulation results show that the above control method has better response characteristics and anti-interference ability, and has better practicability for improving the excavation quality of the grab.

1. Introduction

With the globalization of the economy, water transportation has become increasingly frequent. The lag of the construction and maintenance of ports and waterways and the dredging of inland waterways has increasingly become a prominent problem hindering load trade\cite{1}. As the main tool of the above projects, grab dredger has become increasingly prominent. However, the traditional grab dredger mainly relies on manual operation with the disadvantages of low level excavation accuracy and efficiency\cite{2,3}. In this regard, automated and intelligent grabs is becoming urgent for related market. As an important performance indicator of grab dredger, control method of automatic flat digging is focused in this paper aiming to realize the automatic operation of grab dredgers\cite{4,5}. Based on the research of dredging and grabbing flat excavation and grab flat digging control model, fuzzy PID controllers designed to improve the accuracy and robustness of position control. The effectiveness of related models and algorithms is tested through simulation.
2. Grab flat digging system control model

The composition of the AC position following system is shown in Fig. 1. Owing to the nonlinear and strong coupling characteristics of AC asynchronous motor mathematical model, it is difficult to achieve real-time position tracking only by single closed-loop control. The AC position following system is built on the high-performance (vector control, direct torque control) AC speed control system, that is, based on the high-performance AC speed control system, a position closed loop is set to form a triple loop control system by current, speed and position[6]. So the design of the flat-dip control model follows the flow from the asynchronous motor model to the current loop and speed loop to the position loop of the controller.

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\begin{align*}
\omega_n &= \frac{M}{p_s L_s \Psi_{dr}} \cdot \omega_n^2 + 2 \zeta \omega_n + \omega_n^2 \\
\zeta &= \left( \frac{R_s}{\sigma L_s} + \frac{R_r}{\sigma L_r} \right) \cdot \frac{\sigma L_s J}{2 p_s \Psi_{dr}}
\end{align*}
\]

where \( \Psi_{dr} \) is d-axis component of the rotor flux linkage; \( T_n \) and \( T_l \) are electromagnetic torque and load torque respectively; \( p_n \) is pole logarithm; \( \omega_r \) is rotor angular velocity; \( R_s \) and \( R_r \) are stator and rotor impedances respectively; \( L_s, L_r \) are self-inductance coefficients of both fixed and rotor; \( M \) is mutual inductance; \( \sigma \) is magnetic flux leakage coefficient; \( J \) is moment of inertia; \( D \) is resistance torque damping coefficient. The above asynchronous motor transfer function can be described by the block diagram shown in Fig 2.

![Figure 1. AC position following system structure diagram](image)

![Figure 2. Asynchronous motor transfer function block diagram](image)
The current loop can be functionally viewed as a current follower system that ensure fast and accurate tracking of the stator and rotor currents for vector control commands. Considering the intense influence of current by loads, in order to achieve fast follow-up, the current loop is controlled by a PI regulator, and its dynamic structure diagram is shown in Fig. 3.

Let $\tau_i = T_m$ to offset the zero and pole point, and the small inertia link time constant $T_{\Sigma i} = T_{\Sigma o i}$, then the open and closed loop transfer functions of the current loop are shown in Eq(2) and Eq(3) respectively:

$$G_i(s) = \frac{K_I}{s(T_{\Sigma i} + 1)}$$

$$G_{cl}(s) = \frac{1}{s(T_{\Sigma e} + 1) + K_f}$$

where $K_I = K_p \beta / (\sigma \cdot L_s)$. The speed loop is also an important link, requiring speed control with high level gain and passband, and strong anti-jamming capability. The performance of speed control requires small speed pulse rates, fast frequency response, and wide adjustment range. So PI algorithm is chosen for the controller for its fast response and small steady-state error. The transfer function of current loop can be equivalent to

$$G_{cl}(s) = \frac{1}{s/K_f + 1} = \frac{1}{T_f s + 1}$$

where $T_i = 1/K_i$. The dynamic structure of the speed loop is shown in Fig. 4.

$$G_i(s) = \frac{K_N(\tau_s + 1)}{s^2(T_S s + 1)}$$

Where $K_N = (\tau_d K_d a)/J$. The dynamic structure of the position loop is shown in Fig. 5 that an integral link of reducer is set in forward channel. Through the asynchronous motor model and the triple loop design, the control model of the flat digging system can be obtained. Owing to the current and speed loops have been solidified in vector inverter, corresponding function can be realized just by the functions and parameters setting. From the inside out, the control loop is designed by layers to ensure the stability. In the process of designing, loop-by-loop equivalent transfer function is used because the cutoff frequency of the position loop is lower than that of the speed loop, and the cutoff frequency of the speed loop is lower than that of the current loop. And the cutoff frequency of the position loop will be limited...
to a small amount, which will limit the response speed of the position loop. In order to improve the response speed, PID controller and intelligent control algorithm can be used to improve the accuracy and robustness of position control. Therefore, the design of an efficient position loop control algorithm will become the key point to achieve grab control.

Figure 5. Position loop dynamic structure diagram

3. Fuzzy controller design for grab flat digging system

Traditional PID controller is widely used in process and motion control due to its simple algorithm, robustness and high reliability. However, once the parameters setting, they cannot be changed, so the control effect cannot be satisfied. Therefore, fuzzy PID controller with parameters modified in real time is used to design the position loop can improve the dynamic performance of the control system. The fuzzy PID control structure is shown in Fig. 6.

Figure 6. Fuzzy PID control structure

The key point to realize automatic flat digging is make the motion track of both support rope and open/closed ropes following theoretical value at regular intervals. Therefore, the wire rope position deviation and the position deviation change rate are selected as input variables. The fuzzy PID controller adjusts the three parameters $K_p$, $K_i$ and $K_d$ in real time according to the deviation and the rate of change of the deviation to improve the control performance. Therefore, the three parameters $K_p$, $K_i$ and $K_d$ of the PID are selected as output variables. Considering the fuzzy controller is to be used in the grab flat digging control process, in order to simplify the system, the Gaussian type as shown in Eq(6) is chosen as the fuzzy subset membership function.

$$\mu_A(x) = \exp \left[ -\frac{(x-a_i)^2}{b_i^2} \right]$$

(6)

Where $a_i$ is center value of the function, $b_i$ is width of the function. In general, the requirements of $|e|$ and $|\Delta e|$ for parameters $K_p$, $K_i$, $K_d$ are: 1) When the deviation $|e|$ is large, a larger $K_p$ should be taken to increase the response speed; a smaller $K_d$ is set to avoid beyond the specified range caused by differential super saturation; let $K_i = 0$ removing the integral action to prevent large overshoot and result in integral saturation. 2) When $|e|$ and $|\Delta e|$ are medium-sized, $K_p$ should be smaller value to make the system with appropriate overshoot; $K_i$ takes appropriate value; $K_d$ takes a moderate value to ensure response speed. 3) When $|e|$ is small, increase the value of $K_p$ and $K_i$ to improve the steady state
performance of the system; when $|\Delta e|$ is small, $K_d$ may be larger, and when $|\Delta e|$ is larger, $K_d$ should be smaller to avoid oscillation and improve the anti-jamming performance of the system.

4. Simulation of Fuzzy PID Controller
The control system is simulated by Matlab Simulink module, and simulation block diagram is shown in Fig 7. The input quantity of the PID controller is position deviation and position deviation change rate of support rope by assuming the open and closed rope position always reproduces the theoretical value, and the output of controller is transferred to the grab movement by the grab flat digging system control model to obtain the transfer function, and finally get the position curve of the grab tip. The Fuzzy Logic Controller module invokes the above fuzzy inference system.

Figure 7. Fuzzy PID control system simulation diagram
The selected transfer function of simulation is shown in Fig. 7, and parameters are setting by stable boundary method as: fuzzy factor $k_e = 0.0043$, $k_{ec} = 0.0011$; de-fuzzy factor $k_1 = 10$, $k_2 = -10$, $k_3 = 1$; the initial value of PID is $K_p = 72$, $K_i = 144$, $K_d = 9$; the oscilloscope sampling period is set to 0.01 s. Control curve comparison of normal and fuzzy PID is shown in Fig. 8, from which the fuzzy PID controller has higher overshoot, dynamic and static characteristics than the conventional PID controller.

Figure 8. Control curve comparison of normal and fuzzy PID

5. Conclusion
The AC asynchronous motor is used as the actuator of the control system. Considering the nonlinear and strong coupling properties of the mathematical model, the single closed-loop control method is difficult to achieve the dynamic requirements of position tracking. Therefore, it is necessary to set a position closed loop on the basis of the AC speed control system to form a current, speed and position triple loop control system, which can achieve smooth control. Based on the above control model, the position loop adopts PID controller and fuzzy control algorithm, and the parameters are adjusted in real
time through fuzzy PID, which improves the accuracy and robustness of position control. Therefore, the flat excavation control system has a good effect on improving the excavation quality of the grab dredger.

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