Research on fuzzy PID control of forearm of tunnel steel arch mounting machine

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Abstract. Taking the smooth transition of angular velocity as the key point, the forearm vibration reduction control system based on fuzzy PID control is studied to reduce the influence of the forearm vibration on the docking operation of steel arch. According to the fuzzy rules, the control system establishes the correspondence between the real-time rotation angle error of the forearm and the control signal to reduce the self-vibration caused by the sudden change of the speed at the end of the rotation. By establishing the AMESim-Simulink joint simulation model of the forearm rotation system, the application effect of the fuzzy PID control system on the forearm vibration reduction control is studied. The simulation and experimental results show that this control system effectively reduces the sudden change of the speed and the influence of the self-vibration of the forearm, and each small-angle posture adjustment time can be controlled within 3s.

1. Introduction
The tunnel steel arch mounting machine is a construction machine dedicated to the installation of the support structure (steel arch) in the tunnel. The operator only needs to operate the steel arch mounting machine to complete the connection of the steel arch. The operation divided into two actions, one is that the forearm raises the steel arch to a proper position, and the other action is to rotate the steel arch to connect another steel arch in the horizontal plane[1,2]. However, each connection requires multiple operations, but the traditional PID control system has a slower response speed when the error is still large enough, which increases the adjustment time. Moreover, due to the nonadjustable parameters’ value, the steady-state error is still quite large.

In view of the problems above, this paper establishes fuzzy control rules by studying fuzzy control theory and combining actual engineering conditions [3], which can realize online self-adjustment of control parameters and improve the response speed in certain error regions and the steady-state accuracy, and shorten each docking time.

2. Fuzzy Control Theory
Fuzzy control is a control strategy based on linguistic control rules and fuzzy logic inference methods. According to the subjective concepts such as experience, professional knowledge and control effect expectation, the designer uses the fuzzy relationship between the three control parameters $K_p, K_i, K_d$ of PID and the error value $e$ and the rate of change of the error $ec$ to write fuzzy control rules [4,5]. Then the system uses these rules to adjust the
parameters online, that is, construct a suitable vector from e and ec to U to approximate the ideal control effect\(^6\). The output of the system is:

\[
U(t) = K_p \times e(t) + K_i \times \int e(t) dt + K_d \times \frac{de(t)}{dt}
\]  

(1)

Where \(K_p\), \(K_i\), \(K_d\) are parameters’ value after adjustment.

Based on the Fuzzy control theory, we used Simulink module to design a controller of the forearm vibration reduction control system which is connect to AMESim through the interface module\(^7,8\). In this controller, a Fuzzy Logic Controller is used to perform the fuzzy rules, which can output the adjustment parameters’ value to achieve a better control effect. The controller module is shown in Figure 1.

3. Fuzzy PID Control System Modeling

The advantage of AMESim-Simulink co-simulation is that it omits the cumbersome steps of deriving the transfer function of the system. It only needs to establish the simulation model in AMESim software, and then the system will automatically compile the transfer function by using its interface module\(^9\).

In the design process of the tunnel steel arch mounting machine, considering the safety of operators and machine, only one hydraulic cylinder can be operated at the same time, which simplifies the modeling of the servo system. The components related to the forearm rotation system are built in AMESim software, and the interface module is added to intercommunicate the signal between AMESim and Simulink. The simulation model of the forearm fuzzy control system is shown in Figure 2.
The research idea of this control system is to use an angle sensor to detect the corner signal of the forearm, and then the controller calculates the error value $e$ and the rate of change of the error $\dot{e}$, and last the controller outputs the control current according to the fuzzy control algorithm.

4. Simulation And Experiment
In order to verify the superiority of the fuzzy control system, the fuzzy control system are simulated. According to the actual operation situation, the target value of the forearm angle is simulated by the step signal, and the angle curve and angular velocity curve of the forearm are compared to analyze the effects of the fuzzy control system. The simulation time is set to 20s, and the simulation results are shown in Figure 2 and Figure 3.
Fig. 3 and Fig. 4 show that although the forearm vibration reduction control system slightly extends the forearm angle response time, the angle is almost no oscillation after the end of the rotation, the adjustment time is almost 0. Instead, when the forearm vibration reduction control system is not used, the forearm vibration is obvious after the end of the rotation and the adjustment time is much longer.

Fig. 5 shows that each small angle adjustment response time can be controlled to about 3s with the help of the fuzzy control system, while the traditional control system requires nearly 5s, what’s more, when the forearm rotation system is disturbed, the fuzzy control system can help the forearm return to the steady state faster.

In order to verify the actual control effect of the forearm vibration reduction control system, the tunnel steel arch mounting machine named WXHLC1215 was used as the testing machine. During the experiment, the forearm was rotated at a certain angle to observe the vibration after the end of the rotation, and the response time and adjustment time were recorded, and then we compare and analyze various experimental data to verify the control effect of the control system. The experimental results are shown in Table 1 from where we can see that the use of the control system effectively reduces the vibration of the forearm and shortens the adjustment time of the vibration.

| Target Angle (°) | Control System        | Response Time (s) | Vibration Situation | Adjustment Time (s) |
|------------------|-----------------------|-------------------|---------------------|---------------------|
| 2                | none                  | 0.22              | obvious             | 65.83               |
|                  | Fuzzy Control System  | 3.24              | none                | 0                   |
| 1                | none                  | 0.10              | obvious             | 59.27               |
|                  | Fuzzy Control System  | 2.29              | none                | 0                   |

5. Conclusion
1) The forearm vibration reduction control system based on fuzzy control theory effectively reduces the vibration problem caused by excessive residual speed of the forearm, and the posture adjustment process of the forearm is smoother.
2) The forearm vibration reduction control system based on fuzzy control theory can control the response time to about 3s when the forearm is adjusted at a small angle, and there is no vibration adjustment time.
3) The forearm vibration reduction control system based on fuzzy control theory can restore the system to the steady state more quickly to reduce the influence of the external disturbance.

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