Research on Stability of Sand Core Handling Robot System Based on PID Control

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Abstract. When an industrial robot uses a gripper with half hardness and flexibility to carry a hollow sand core, mechanical vibration will cause the gripper to grasp the sand core unsteadily or cracks in the sand core due to excessive pressure. In this paper, the mathematical model is constructed based on the elements such as gripper structure, clamping pressure and mechanical vibration, the system stability is analyzed, the PID controller is added for correction, the parameter values of $K_p$, $T_i$ and $T_d$ are set by Ziegler-Nichols method, the transfer function of PID controller is obtained, and then the corrected system function is calculated. The dynamic response performance of the system is simulated and analyzed by Matlab / Simulink, the parameters in the PID controller are adjusted, and the overshoot of the system is reduced from 85% to 25%, which effectively reduces the impact of mechanical vibration interference on the sand core and realizes the optimal control of the system.

Keywords. Vibration, PID controller, Ziegler Nichols method, System stability.

1. Introduction

With the proposal of made in China 2025, intelligent manufacturing has become the main development direction in the future. The waste gas, dust, noise and vibration in the casting section of the engine production workshop seriously affect the physical and mental health of on-site production personnel. The use of industrial robots for material handling and assembly is conducive to improving production efficiency [1]. Industrial robots are used for loading and unloading, which has extremely high requirements for the handling of hollow sand core. The clamping force is too large, which is easy to crack the sand core, resulting in a high scrap rate for the cast iron casting behind; If the clamping force is reduced and the sand core clamp is unstable, the sand core will fall and affect the production efficiency. At present, domestic and foreign enterprises use the rubber aluminum plate gripper with alternating flexibility and hardness to carry the sand core, so as to reduce the vibration of the sand core caused by the turnover movement of the gripper, but the ratio of flexibility and hardness is difficult to control, the flexibility is too large, and the sand core clamping is unstable; Excessive flexibility and cracked sand core seriously affect the quality of subsequent cast iron.

This paper takes the core making section of the casting center of Guangxi Yuchai Machinery Co., Ltd. as the carrier, and uses the industrial robot to assemble the engine cylinder head products with different sizes of four and six cylinders as the carrier. In view of the mechanical vibration of the gripper in the process of turnover, acceleration and deceleration, which leads to the falling of the upper
and lower sand core and internal cracks, this paper makes a stability analysis, which is corrected by adding a PID controller. Reduce the overshoot of system oscillation, reduce the impact of external interference impact on the hollow sand core, and ensure that the hollow sand core does not have cracks, so as to improve the quality of the sand core.

2. Building System Mathematical Model

According to the working principle and mechanical structure of the gripper of the industrial robot in the casting center and considering the interference and impact factors such as mechanical vibration, a mathematical model of the closed-loop negative feedback control system is constructed [2-3], as shown in figure 1.

\[ G_1(s) = \frac{K}{T_1 s + 1} \]  

\[ G_2(s) = \frac{\lambda}{T_2 s + 1} \]

The open-loop transfer function of the system is \( G_k(s) \), and the closed-loop transfer function of the unit negative feedback of the system is \( G(s) \).
Bring equation (3) into equation (4) and find out that the closed-loop transfer function of unit negative feedback of the system is the value of $G(s)$.

\[ G(s) = \frac{G_1(s)}{1+G_1(s)} \]  \hspace{1cm} (4)

Bring $G_1$ and $G_2$ into the system mathematical model. If the system input signal and interference signal are unit pulses, simulate and analyze the system model through MATLAB / Simulink. Under the action of interference impact [4], the system response output waveform of system $G(s)$ is shown in figure 2.

![Figure 2. Unit impulse response waveform of original system.](image)

The simulation results show that the system oscillates under external interference, and the overshoot is $\sigma = 85\%$, the stable adjustment time is $T_s = 5s$, and the system is greatly affected by external interference and impact. It is precisely because of the system oscillation that the hollow sand core is subjected to uneven stress and cracks, which brings a great scrap rate to the rear cast iron casting. Therefore, it is necessary to add a PID controller to correct the system, reduce the oscillation caused by interference and reduce the overshoot $\sigma$.

3. Add PID Control

The system is driven by the air pressure input link to overcome the impact interference of overturning vibration and acceleration and deceleration, and measure and feed back the output of the gripper to reduce the deviation [5-6]. According to the working mode of industrial robot handling sand core, affected by the structure of gripper, clamping pressure and flexibility of clamping surface, the mathematical model of adding PID controller is proposed, as shown in figure 3.
Figure 3. The principle diagram of PID control.

After adding PID control to the system transfer function, a linear system model is formed, as shown in figure 4.

Figure 4. Block diagram of transfer function of system.

As a linear controller, the PID controller forms a control deviation according to the given value \( Y_d(t) \) and the actual output value \( Y(t) \).

\[
error(t) = Y_d(t) - Y(t)
\]  
(6)

The PID control law is \( u(t) \).

\[
u(t) = K_p \left[ error(t) + \frac{1}{T_i} \int_0^t error(t) dt + T_d \frac{derror(t)}{dt} \right]  
\]  
(7)

The form of transforming PID control law into transfer function is \( G(s) \).

\[
G(s) = \frac{U(s)}{E(s)} = K_p \left( 1 + \frac{1}{T_i s} + T_d s \right)
\]  
(8)

Here, the parameter values of proportional coefficient \( K_p \), integral time \( T_i \) and differential time \( T_d \) in PID are required. Since the system is a second-order system, according to the characteristics of the second-order system and combined with the specific performance indexes of the system, Ziegler-Nichols tuning method is used to calculate the parameters of PID [7-8].

Ziegler-Nichols tuning method determines the parameters of PID controller according to the transient response characteristics of a given object. In mathematical modeling, \( K_p \) is the coefficient of proportional amplification link, \( T_i \) integral link and ‘Tou’ is the time coefficient of differential link. Firstly, through Simulink simulation, disconnect the system feedback line, the output line of differentiator and the output line of integrator, and set the value of \( K_p \) to 1, as shown in figure 5.
Figure 5. Block diagram of open loop unit step response of system.

Run the simulation to obtain the open-loop unit step response of the system, as shown in figure 6.

Figure 6. Open loop unit step response curve of the system.

The calculation method of PID parameters according to Ziegler-Nichols setting S-shaped response curve is shown in figure 7.

Figure 7. Determination of PID parameters by open loop step response curve.

By determining the PID parameters through the open-loop step response curve, the system delay time $l$, amplification factor $K$ and time constant $T$ can be roughly obtained, $L=0.2s$, $T=4.3-0.2=4.1s$, 

K = 1350.

According to Ziegler-Nichols setting parameter table, the parameter values of $K_p$, $T_i$ and $T_d$ in PID can be obtained.

### Table 1. Ziegler-Nichols method for tuning controller parameters.

| Controller type | Proportionality $\gamma$%($K_p$) | Integration time $T_i$/s($T_i$) | Differential time $T_d$/s($T_d$) |
|-----------------|-----------------------------------|---------------------------------|----------------------------------|
| P               | $\frac{T}{(K \times L)}$          | $\infty$                        | 0                                |
| PI              | $0.9 \frac{T}{(K \times L)}$      | $\frac{L}{0.3}$                 | 0                                |
| PID             | $1.2 \frac{T}{(K \times L)}$      | $2.2L$                          | $0.5L$                           |

Bring $T$, $K$ and $L$ into table 1 and calculate the corresponding parameters of PID proportional, integral and differential links. The value of proportional link $K_p=1.2T/KL=0.02$, integral time $T_i=2.2L=0.44s$, and differential time $T_d=0.5L=1s$. Because the engineering experience Ziegler-Nichols method is used to set PID parameters, the calculated value is not the most ideal value in practical application, but also needs to be adjusted and optimized in the field application [9-10].

### 4. Control System Calibration

The PID control parameters $K_p=0.02$, $T_i=0.44s$ and $T_d=1s$ are calculated by Ziegler Nichols method. Matlab / Simulink is used for simulation to bring the adjusted PID parameters $K_p$, $T_i$ and $T_d$ into the mathematical modeling. Set the value of the commissioning proportional amplifier to $K_p=0.02$, the value of the integrator to $T_i=0.44s$, and the value of the differentiator to $T_d=1s$, and then connect the differentiator, integrator and feedback first, as shown in figure 8.

![Figure 8. Control system model after series PID calibration.](image_url)
The optimized PID control parameters are substituted into equation (9), and the actual transfer function of the series PID controller is \( G_c(s) \).

\[
G_c(s) = \frac{2.75s^2 + 5.5s + 3.3}{s} \quad (10)
\]

The open-loop transfer function of the control system corrected by the series PID controller is \( G'_c(s) = G_c(S)G_r(s)G_s(s) \).

\[
G'_c(s) = \frac{1848s^2 + 3696s + 2217.6}{s^3 + 2s^2 + 673s} \quad (11)
\]

After the system is connected with PID in series, the closed-loop transfer function of unit negative feedback of the system is \( G(s) = \frac{G_k}{1+G_k} \).

\[
G(s) = \frac{1848s^2 + 3696s + 2217.6}{s^3 + 1850s^2 + 4369s + 2217.6} \quad (12)
\]

Run the simulation. After running, double-click the oscilloscope "scope" to view the response output of the system after series PID correction, and get the waveform shown in figure 9.

![Figure 9. Waveform after series PID correction.](image)

It can be seen from Figure 9 that the system tends to be stable after only one oscillation. The overshoot of the system after series PID correction \( \sigma=1550\% \), adjustment time \( T_s=14s \), because the system overshoot is too large, it has a great impact on the quality of sand core, so it is necessary to continue to fine tune the PID parameters in the engineering test [11-12].

According to the PID parameter setting, the integral term should not be too small, which will easily lead to the difficult elimination of the steady-state error of the system and affect the adjustment accuracy of the system, and the integral term should not be too large, otherwise it will increase the response oscillation, prolong the adjustment time, and reduce the anti-interference performance of the system. Through experience and manual fine adjustment, when the PID control parameters \( K_p=5.5 \), \( T_i=0.6s \) and \( T_d=0.5s \), the system response is shown in figure 10.
According to experience, after fine tuning the system response output waveform, the system quickly tends to be stable after only one small oscillation, and the system overshoot decreases to $\sigma=25\%$, which can effectively suppress the mechanical vibration caused by the turnover, acceleration and deceleration of the robot gripper.

The experimental conclusions are shown in table 2.

Table 2. Performance indexes of system.

| System Type          | Closed loop transfer function of system | Controller parameters | Performance index |
|----------------------|----------------------------------------|-----------------------|-------------------|
| Uncorrected system   | $G(s) = \frac{672}{s^2 + 2s + 673}$    | $K_p=5.5, T_i=0.6s, T_d=0.5s$ | $\sigma=85\%, T_s=5s$ |
| PID corrected system | $G'(s) = \frac{1848s^2 + 3696s + 2217.6}{s^3 + 1850s^2 + 4369s + 2217.6}$ | $\sigma=25\%, T_s=6s$ |

Taking the casting center of Guangxi Yuchai Machinery Co., Ltd. as the test object, after a period of on-site test, the stable adjustment time is $T_s=6s$, which is 1s longer than before, but the system after correction and adjustment is less affected by interference impact and overshoot $\sigma=25\%$, compared with that before PID controller correction $\sigma=85\%$, the overshoot is reduced by 3.4 times, the influence of interference impact on the sand core is greatly reduced, and the qualified rate of the sand core is guaranteed.

5. Conclusion

In this paper, through the stability analysis of the industrial robot loading and unloading of the core making machine, through the analysis of the impact of the sand core disturbed by the mechanical vibration of the gripper, it is proposed to add a PID controller for correction. Using Ziegler-Nichols setting method and field test, the PID correction parameters and the corrected system function are obtained. The corrected system response is analyzed by Simulink to fine tune $K_p$, the optimal control system is obtained from the parameter values of $T_i$ and $T_d$, which reduces the system overshoot from...
85% to 25%, reduces the overshoot by 3.4 times, effectively reduces the impact of external interference on the sand core, and improves the qualified rate of the sand core. The results show that when the industrial robot is used to transport the hollow sand core produced by the core making machine in the core making section of the engine production casting center, the research results of this paper have great reference value for the stability of the control system of the handling robot.

Acknowledgment
Fund Project: 1. National Natural Science Foundation of China (51567004); 2. The basic scientific research ability improvement project for young and middle-aged teachers in Colleges and universities in Guangxi in 2021 (2021ky1080): "research and application of flexible gripper for assembly robot in casting center".

Reference
[1] Lin X X, Li G J and Zhou S K 2020 Research and analysis clamp stability of core making robot based on Matlab Manufacturing Technology & Machine Tools 03 109-113
[2] Xu K 2017 Control of nonlinear modular mobile Robots using PID method with iterative feedback tuning Machinery Design & Manufacture 05 230-233
[3] Zhou Z, Chen Y X and Chen X 2021 Control system of automobile chassis dynamiter based on BP + RNN variable speed integral PID algorithm Machinery Design & Manufacture 02 148-152
[4] Wang H L and Guo L 2008 Research on control strategy and Simulation of nonlinear vehicle suspension based on Fuzzy Immune PID Journal of Mechanical Strength 06 911 -915
[5] Zhang Y, Gong Y G and Tian T 2020 Application of PI Ziegler-Nichols Predictive Control in Robot Position Control Machinery Design & Manufacture 03 269-271.
[6] Lin X X 2021 Simulation research on motion connection system of omnidirectional mobile robot based on PID control Food & Machinery 37 102-104+111
[7] Pradhan R, Majhi S K, Pradhan J K and Pati B B 2019 Optimal fractional order PID controller design using Ant Lion Optimizer Ain Shams Engineering Journal 10 281-291
[8] Qian S, Lam H K, Xuan C B and Chen M 2020 Adaptive neuro-fuzzy PID controller based on twin delayed deep deterministic policy gradient algorithm Neurocomputing 03 183-194
[9] Xu J X, Zhang M, Wang Y and Cheng C 2019 Constant current charging control system of energy storage capacitor based on BP neural PID Control Engineering of China 16 228-230
[10] Luo H P, Ji J, Yang H R and Sun L Y 2019 Research on Fuzzy PID Control for Feed Servo System of CNC Machine Tool Machinery Design & Manufacture 12 159-162
[11] Peng A H and Xiao X M 2013 PID parameter tuning of machine tool servo system based on response surface model Journal of Mechanical Strength 35 263-269
[12] Hu M H and Li H F 2020 Design of picking robot manipulator control system based on Fuzzy PID Journal of Agricultural Mechanization Research 08 245-248