Research on multi-core DSP cooperative control system in environmental protection equipment

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Abstract: Traditional multi-servo motor control systems have the problems of poor output stability in environmental protection equipment, weak robustness, and low control ability. Based on this, the research of multi-servo motors control systems based on FPGA are proposed. The paper Construct a parameter distribution models on multi-servo motor control, using motor terminal voltage, current, and back-EMF as control constraints, calculate the difference between the output currents of the multi-servo motors, and construct a saturation function to analyze the multi-servo motor control objective function. Sampling phase current signal and PWM duty cycle as modulation parameters, combined with fuzzy adaptive PID control method to control the output robustness of multiple servo motors, calculating the equivalent mechanical power and equivalent electromagnetic power of multiple servo motors. The optimized parameter adjustment method performs self-tuning processing of the motor output, and the transient stability adjustment of the multi-servo motor is performed based on the method of the average terminal voltage analysis to realize the optimal design of the multi-servo motor control law. The test results show that the output stability of the output of the multi-servo motor control system using this method is better, the motor control is more robust and the control ability is higher.

1. Introduction
The multi-path servomotors in environmental protection equipment, taking full advantage of permanent magnets and transducers, carry out multi-path servo synchronous conversion[1]. In the design of multi-path servomotors, however, it sees poor stability of the output power due to unstable output power, and the output power of the multi-path servomotors needs to be optimized and controlled. Therefore, it is of great significance to study the control method of multi-path servomotors in the course of design and application[2].

Reference [3] builds a mathematical model for servomotor system of the laser beam radiation, and utilizes a fuzzy logic algorithm combined with PID control to realize the dynamic performance simulation experiment of the servomotor. In this connection, the servomotor system has good dynamic performance (output stability of the servomotor is not considered). Reference [4] establishes a closed-loop control system for current, position and speed. Based on the overall structure of the multi-axis servomotor, the mapping of the EtherCAT application layer is designed and a detailed design process is provided. Through experimental testing and analysis of fixed and tracked positions, the servo system, with high accuracy, can realize multi-motor synchronous coordinating control. However, this method does not take into account weak motor control robustness. Reference [5] shows in the LabVIEW program development environment, the control system operation is completed by the industrial personal computer. The upper computer is used to adjust the parameters, and the MPScope software to complete
the communication between the industrial personal computer and the motion controller, thus taking control on the multi-axis motor. This method can effectively reduce the development cycle of the multi-axis servomotor control system with simple structure and high scalability, but the stability of such method needs to be studied.

In response to the above problems, this paper first presents research on control system of multi-path servomotor on FPGA, builds a parameter distribution model for multi-path servomotor control, and samples phase current signal and PWM duty cycle as modulation parameters; then takes output robustness control of multi-path servomotors in combination with fuzzy adaptive PID control method, calculates the equivalent mechanical power and equivalent electromagnetic power of multi-path servomotors, uses the optimized parameter adjustment method to perform self-tuning of the motor output, and conducts transient stability adjustment of multi-path servomotors based on mean value analysis of terminal voltage; finally achieves optimized design of control system of multi-path servomotors combined with FPGA, and carries out the simulation test analysis to come to effective conclusions.

2. Analysis of equivalent circuit and control constraint parameters under multi-path servomotor control

2.1. Analysis of equivalent circuit under multi-path servomotor control

For optimization of multi-path servomotor control, we should first build a parameter distribution model for multi-path servomotor control, take motor terminal voltage, current and back electromotive force as control constraint parameters, and optimize the adjustment control parameters; then use the primary and secondary side circuits for electromagnetic coupling adjustment \(^{[6]}\), establish the electromagnetic coupling control model of multi-path servomotor control, and finally establish its equivalent circuit model to obtain the equivalent circuit, as shown in Fig. 1.

![Fig. 1 Equivalent Circuit under Multi-path Servomotor Control](image)

According to Fig. 1, the T-shaped equivalent circuit diagram is introduced to build an output conversion control model of the multi-path servomotor, and the transient stability analysis method of the generator power angle to adaptively adjust the output power of the multi-path servomotor. Combined with the parameters of the motor's output power, electromagnetic torque and power gain, a constraint parameter model is thereby established for the electromagnetic torque coupling control of the multi-path servomotor to obtain the coupling parameter model:

\[
N = \pi k_e (2r_r + k_t^2) \tag{1}
\]

In formula (1), \( k_e \) represents the power output transfer coefficient of the multi-path servomotor, and \( r_r \) represents the exciting voltage generated. The magnetic flux output from the multi-path servomotor, combined with the feedback gain adjustment method, is:

\[
B_e = \frac{F_m}{A_g R} \tag{2}
\]

In formula (2), \( F_m \) represents the reactive loop PI control parameter, \( A_g \) represents the winding gap area, and \( R \) represents the phase angle of the rotor reference voltage. Calculate the difference between the output phase currents of multi-path servomotors, build a saturation function to analyze the equivalent circuit of the multi-path servomotor control, establish an equivalent circuit model, and optimize the motor control design \(^{[7]}\).
2.2. Analysis of control constraint parameters under multi-path servomotor control
In combination with the analysis method of inertial response characteristics of the motor system, the calculated inertia characteristics and frequency response of the system, the magnetic field capacitance $C_r$ and winding capacitance $C_s$ of the motor are obtained. The fuzzy parameter of the continuous compensation control of the multi-path servomotor is:

$$L = \frac{F_n}{C_r R} \pi k_r (2r_s + C_s^2)$$  \hspace{1cm} (3)

After analyzing the inertia characteristics of the multi-path servomotor system, and taking the compensation control method of electromagnetic coupling into consideration, the impedance of the multi-path servomotor is:

$$Z_m = \frac{B_{eq}}{C_s R} + \left( \pi k_r - \frac{1}{RC_s} \right)$$  \hspace{1cm} (4)

Upon equivalent transformation of rotor voltage, and stator and rotor current, the output coupling of the multi-path servomotor can be adjusted by using MUR1620CT as the regulator, and the inertial gain of the synchronous motor is:

$$G_r = \left[ (R_{eq} - Z_m^2 + C_s^2) \right]^{\frac{1}{2}}$$  \hspace{1cm} (5)

In formula (5),  $R_{eq}$ is the disturbance quantity of stator current. Combined with the joint estimation method of stator and rotor voltage, the output stability of the multi-path servomotor can be well controlled, and the saturation tracking error of the output voltage of the multi-path servomotor is:

$$Z_s = \frac{R_{eq}}{G_r + Z_m}$$  \hspace{1cm} (6)

An error compensation function is constructed for adjustment on the steady state of the output of the multi-path servomotor. The phase current signal and PWM duty cycle are sampled as modulation parameters, and the output robustness of the multi-path servomotor is controlled under fuzzy PID control method [8].

3. Algorithm optimization of multi-path servomotor control
3.1. Adaptive adjustment of control parameters
Calculate the equivalent mechanical power and equivalent electromagnetic power of multi-path servomotors, use the optimized parameter adjustment method to perform self-tuning of the motor output, and adaptively adjust the output power of the electromagnetic torque of the multi-path servomotor. The method of small-signal disturbance transmission is used to control the motor torque, and the optimal adjustment model of the rotor current and voltage of the multi-path servomotor is:

$$F_n = \frac{R_{eq} Z_m + 1}{\mu_0 \mu_1 \mu_2}$$  \hspace{1cm} (7)

In formula (7),  $\mu_0 = 4\pi \times 10^{-7}$ H/m represents the vacuum permeability of the electromagnetic coupler of the multi-path servomotor, and $\mu_1$ and $\mu_2$ represent the magnetic permeability of the permanent magnet and winding of the multi-path servomotor respectively. The adaptive backstepping control method is introduced to calculate the rotor resistance, stator and rotor equivalent self-inductance and mutual-inductance [9]. The electric potential and phase current of the motor are as follows:

$$R_{eq} = \frac{\mu_0}{3} \frac{1}{\omega \mu_1}$$  \hspace{1cm} (8)

$$R_{eq} = 4L \frac{N \mu_2}{\pi (2r_s + k_s^2)}$$  \hspace{1cm} (9)

In formula (8),  $\omega$ represents the self-inductance coefficient of the phase winding. The input
saturation error of the multi-path servomotor is uncertain, therefore, the anti-saturation compensation is performed on the entire multi-path servomotor to realize the adaptive adjustment of control parameters.

3.2. Optimization of control law
Under the condition of limited steady state error, an optimal control model of a multi-path servomotor is built. The output resistance of the multi-path servomotor is \( R_{\psi} \) and the coupling damping torque of the motor is:

\[
W = \frac{8G_{r}^{2}}{\pi^{2} R_{\psi}}
\]

Disturbance rejection is carried out under a piecewise saturation function inside and outside the boundary layer, the self-tuning of the motor output is performed in line with the optimized parameter adjustment method, and the transient stability adjustment of multi-path servomotors based on mean value analysis of terminal voltage is conducted\(^{10}\). Considering the leakage coefficient \( k_{i} \) and the span coefficient \( k_{p} \), the torque output of the multi-path servomotor can be represented as:

\[
T_{\text{em}} = \frac{\pi k_{r} k_{c} (2r + k_{c}^{2})}{\ln \left( \frac{r + Z_{m}}{R_{eq}} \right)}
\]

Eventually, the output power loss of the multi-path servomotor is:

\[
P_{\text{loss}} = T_{\text{em}} (k_{c} + R_{sc} + 2R_{dc}) + T_{\text{em}} (k_{c} + R_{eq} + 2k_{p})
\]

The optimized motor control law is:

\[
f_{o}(X) = F_{o} \left( 1 - \frac{\omega_{o}}{T_{\text{em}}} \right) + F_{o} \left( \frac{1}{B_{o}} - \varepsilon \right)
\]

In formula (12), \( \varepsilon \) is a small constant, and the least square method is used for optimizing. The optimized node vector \( f_{o}(\chi) \) is:

\[
f_{o}(\chi) = \frac{1}{T_{\text{em}} + f_{o}(X)}
\]

The transient stability adjustment of multi-path servomotors based on mean value analysis of terminal voltage is conducted to achieve the optimal design of the control law of the multi-path servomotor. The optimal control function is:

\[
F(x) = \sum_{i=1}^{N} F_{i} \left( R_{c} - \frac{\omega_{o}}{T_{\text{em}}} \right)
\]

Adaptive linear weighting is used to achieve optimal control of multi-path servomotors.

4. Design of system hardware
On the strength of the control algorithm design mentioned above, the design of system hardware can be carried out. The control system of multi-path servomotor uses FPGA as the main control chip. The source protection module of the control system of multi-path servomotor is designed, and the grounding resistance measurement module is constructed to perform the output conversion control of the control system of multi-path servomotor. The control method of DC constant current output is introduced to carry out bus transmission of control system of multi-path servomotor, and RS5485 bus monitoring method to perform information security baseline configuration of control system of multi-path servomotor. The hardware structure of the system is shown in Fig. 2.
By virtue of the integrated design method, the information security baseline configuration and human-computer interaction interface design of the control system of multi-path servomotor can be realized in the ROM. The hardware design of the system obtained is shown in Fig. 3.

5. Simulation test analysis
To test the application performance of the method in this paper in the matter of realizing multi-path servomotor control, an experimental test analysis was conducted. In the experiment, the input voltage of the multi-path servomotor is 240V, the potential observation is 480V, the average terminal voltage is 120V, and the output current of the motor is 50A, the rated torque is 0.24N m, the initial power is 300KW, the reference speed and feedback speed are 
\[ G(s) = \frac{1}{55s + 1} e^{-122s} \], and the magnetic permeability is \( \mu_0 = 4\pi \times 10^{-7} \) H/m. According to the above simulation environment and parameter setting, the multi-path servomotor control is performed, and the output power angle of generator is tested, as shown in Fig. 4.
Fig. 4 Output Power Angle of Generator

It can be seen from Fig. 4 upon analysis that the method in this paper in the matter of realizing multi-path servomotor control shows better convergence, and the gain of the output power angle of generator is larger with high stability. The phase current signal and PWM duty cycle are tested, as shown in Fig. 5.

Fig. 5 Phase Current Signal and PWM Duty Cycle

It can be seen from Fig. 5 upon analysis that the method in this paper in the matter of realizing multi-path servomotor control improves the output power and efficiency, with strong robustness. The output gain of the motor is further tested, as shown in Table 1.

| Number of iterations | Method in this paper | Reference [3] | Reference [4] |
|----------------------|----------------------|---------------|---------------|
| 100                  | 23.4                 | 18.2          | 21.2          |
| 150                  | 26.5                 | 19.1          | 24.3          |
| 200                  | 29.2                 | 22.3          | 27.5          |
| 250                  | 31.2                 | 27.4          | 29.4          |

It can be seen from Table 1 upon analysis that as the number of iterations increases, the gain decibels of the method, Reference [3], and Reference [4] in this paper all increase. However, the incremental decibel of the method in this paper is higher than that in Reference [3] and Reference [4], indicating that the output power of the multi-path servomotor control in this method is relatively high.

6. Conclusions
This paper presents a design on multi-core DSP cooperative control system in environmental protection.
equipment, and makes a parameter stability analysis on output power regulation and optimal control of multi-path servomotor under output parameter adjustment method. It also takes output robustness control of multi-path servomotors in combination with fuzzy adaptive PID control method, calculates the equivalent mechanical power and equivalent electromagnetic power of multi-path servomotors, and uses the optimized parameter adjustment method to perform self-tuning of the motor output in a bid to realize the optimal design of the multi-path servomotor control. The method in this paper in the matter of realizing multi-path servomotor control improves the output power and efficiency of the control system of multi-path servomotor, together with good stability and strong robustness.

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