Research on Arc Voltage Distance-Regulating System for TIG Welding Robot

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Abstract. In order to meet the demand of TIG welding robot for high precision and high real-time, this paper presents the arc voltage distance-regulating system using expert controller. By precisely controlling the distance between the tungsten electrode and the welding seam, the arc voltage is precisely controlled, and the closed-loop control of arc voltage is realized. The simulation and experiment of MATLAB show that the arc voltage distance-regulating system's arc voltage control accuracy is $18\pm0.8V(6\pm0.32mm)$, which meets the precision requirements of welding robot's arc voltage control and significantly improves the welding quality.

1. Introduction

TIG welding is widely used in thin plate welding. In order to ensure the quality of welding, the arc voltage must be stable within a certain range. In the process of TIG welding robot welding thin plate, the thin plate will produce large thermal deformation, welding leakage, welding nodule and other welding defects, so it must use the arc voltage distance-regulating system to adjust the welding arc voltage. Since the deformation of the thin plate during welding is nonlinear, the arc voltage variation is also nonlinear. Therefore, the arc voltage distance-regulating system of TIG welding robot cannot adopt the common PID control algorithm\cite{1}, so this paper adopts the expert PID control algorithm\cite{2}. The relationship between arc voltage and arc length during TIG welding can be expressed as $U_h=U_z+K\cdot L$. In the equation, $U_h$ is the arc voltage; $U_z$ ($U_z=3V$) is the sum of cathode voltage drop and anode voltage drop under a certain condition (a certain current and electrode material); $K$ ($K=0.4$) represents the proportional constant, arc voltage gradient; $L$ is the distance from the tungsten to the weld. It can be seen that the arc voltage is dependent on the change in the length of the arc. When the arc is elongated, the arc voltage rises, and as the arc length becomes shorter, the arc voltage decreases.

2. Overall design of the arc voltage distance-regulating system

During the process of sheet welding, the distance between the welding gun and the surface of the sheet changes constantly due to the thermal deformation of the sheet, which results in the change of arc voltage (arc voltage is directly proportional to the distance between the welding gun and the welding surface). Because the stable arc voltage has a very important influence on the welding quality, the stability of arc voltage in the welding process can greatly improve the welding quality. Therefore, this paper designs the arc voltage distance-regulating system. The arc voltage distance control system is mainly composed of LMS filter and expert controller. The expert controller is divided into expert PID controller and speed controller of distance-regulation. The real-time performance of the arc voltage distance-regulating system can be effectively improved by the speed controller in the expert controller\cite{3}. The welding arc voltage can be stabilized in a reasonable range through the reasonable coordination of these two parts.
First, the arc voltage acquisition board of the arc voltage distance-regulating system (as shown in Fig.1) compresses the collected arc by 10 times. Then, the arc voltage is subjected to LMS filtering to obtain a smoothly varying arc voltage. Finally, the smooth arc voltage is transmitted as an input signal to the expert controller to control the stepping motor, and the distance from the tungsten electrode to the weld is adjusted to achieve arc voltage regulation.

![Figure 1. The arc voltage distance-regulating system](image1)

![Figure 2. The LMS filtering algorithm](image2)

LMS filter is actually a special Wiener filter that can automatically adjust its own parameters[4]. It does not need to know the statistical characteristics of the input signal and noise in advance when calculating, but can gradually estimate the required statistical characteristics in the process of work, and automatically adjust its own parameters based on this to achieve the best filtering effect[5]. Once the statistical characteristics of the input signal change, it can track the change, automatically adjust the parameters, so that the filter performance to achieve the best[6].

The LMS filtering algorithm is shown in Fig.2. In the equation, $x(k)$ is the input signal; $d(k)$ is the reference signal; $e(k)$ is the error signal; $\mu$ is the convergence factor; $w(k)$ is the weight; $y(k)$ is the output signal. Output smooth signal after n iterations. Since the calculation process of the convergence factor is more complicated, in the actual application process, it is generally tested according to the actual situation, and the convergence factor with better filtering effect is obtained. The convergence factor is obtained through the MATLAB simulated analysis.

After filtering, the arc voltage signal will be transmitted to the expert controller, and the expert intelligent control is established on the knowledge of the controlled object and control law, without knowing the accurate mathematical model of the controlled object, and using the expert experience to design the parameters in the system. Expert intelligent control is a kind of direct expert controller. In the direct expert control system, the control signal is given directly by the system, which affects the whole controlled process. The direct expert control system derives the control signal at each sampling time according to the process information and rules in the knowledge base. As shown in Fig.3, the expert intelligent control system is composed of input and output sampling signals, knowledge base, information acquisition and processing, reasoning mechanism and control rule set. The expert controller processes the sampled signals, and then repeatedly matches them with the control rules in the knowledge base to obtain the corresponding results, and then controls the controlled objects for output.
The actual welding arc voltage and the optimal welding arc voltage, which is measured at the $U_{\text{max}}$

**Table 1. The expert PID control rules**

| $E_{\text{max}}$, $+\infty$ | $\Delta e(k)$ | $\Delta e(k-1)$ | $u(k)$ |
|---|---|---|---|
| $[E_{\text{set}}, E_{\text{max}}]$ | $\geq 0$ | $u(k-1) + k_1 \Delta e(k) + k_2 \Delta e(k) + k_3 \Delta^2 e(k)$ |
| | $< 0$ | $\leq 0$ | $u(k-1)$ |
| $(0, E_{\text{set}})$ | $\geq 0$ | $\leq 0$ | $u(k-1) + k_2 \Delta e_m(k)$ |
| $(E_{\text{set}}, 0)$ | $> 0$ | $u(k-1) + k_1 \Delta e_m(k)$ |
| $(E_{\text{min}}, E_{\text{set}})$ | $\geq 0$ | $< 0$ | $u(k-1) + k_1 \Delta e_m(k)$ |
| $(-\infty, E_{\text{min}})$ | $\leq 0$ | $u(k-1) + k_2 \Delta e_m(k)$ |

$E_{\text{max}}$, $E_{\text{min}}$, $E_{\text{set}}$, $E_{\text{set}}$, $E_{\text{set}}$ are the deviation boundary, and $E_{\text{max}} < E_{\text{set}} < 0 < E_{\text{set}} < E_{\text{max}}$; $k_1$ is the gain factor, and $k_1 > 1$; $k_2$ is the inhibiting factor, and $0 < k_2 < 1$; $k_3$, $k_4$, and $k_5$ are the proportional, integral, and differential coefficients of the PID control, respectively.

**Table 2. The speed control rule of distance-regulation**

| $e(k)$ | $V_e(k)$ | $V(k)$ |
|---|---|---|
| $[E_{\text{max}}, +\infty]$ | $[V_{\text{set}}], V_{\text{max}}$ | $V_1$ |
| | $(V_{\text{set}}, V_{\text{set}})$ | $V_2$ |
| | $(0, V_{\text{set}})$ | $V_3$ |
| $(E_{\text{set}})$ | $[V_{\text{set}}], V_{\text{max}}$ | $V_4$ |
| | $(V_{\text{set}}, V_{\text{set}})$ | $V_5$ |
| | $(0, V_{\text{set}})$ | $V_6$ |
| $(0, E_{\text{set}})$ | $[V_{\text{set}}], V_{\text{max}}$ | $V_7$ |
| | $(V_{\text{set}}, V_{\text{set}})$ | $V_8$ |
| | $(0, V_{\text{set}})$ | $V_9$ |
| $0$ | $[V_{\text{set}}], V_{\text{max}}$ | $V_{10}$ |
| | $(V_{\text{set}}, V_{\text{set}})$ | $V_{11}$ |
| | $(0, V_{\text{set}})$ | $V_{12}$ |
| $(E_{\text{set}}, 0)$ | $[V_{\text{set}}], V_{\text{max}}$ | $V_2$ |
| | $(V_{\text{set}}, V_{\text{set}})$ | $V_4$ |
| | $(0, V_{\text{set}})$ | $V_6$ |
| $(E_{\text{set}}, E_{\text{set}})$ | $[V_{\text{set}}], V_{\text{max}}$ | $V_4$ |
| | $(V_{\text{set}}, V_{\text{set}})$ | $V_5$ |
| | $(0, V_{\text{set}})$ | $V_7$ |
| $(E_{\text{min}}, E_{\text{set}})$ | $[V_{\text{set}}], V_{\text{max}}$ | $V_5$ |
| | $(V_{\text{set}}, V_{\text{set}})$ | $V_6$ |
| | $(0, V_{\text{set}})$ | $V_8$ |

$V_{\text{set}}$, $V_{\text{max}}$, $V_{\text{max}}$, $V_{\text{min}}$, $V_{\text{min}}$ are the speed boundary, and $V_{\text{max}} < V_{\text{set}} < V_{\text{set}} < 0 < V_{\text{set}} < V_{\text{max}}$.

3. **Establishment of the arc voltage distance-regulating system algorithm**

Let $e(k) = U_{\text{set}} - U(k)$. In the equation, $U_{\text{set}}$ is the optimal welding arc voltage of TIG welding robot; $U(k)$ is the actual welding arc voltage, which is collected by the arc voltage acquisition board at the $k$-th sampling time; $e(k)$ is the deviation between the actual welding arc voltage and the optimal welding arc voltage, which is measured at the $k$-th sampling time; $e(k-1)$ and $e(k-2)$ are the deviations between the actual welding arc voltage and the optimal welding arc voltage, which is measured at the $(k-1)$-th and $(k-2)$-th sampling moments, in addition

$$
\Delta e(k) = e(k) - e(k - 1),
\Delta e(k - 1) = e(k - 1) - e(k - 2),
\Delta^2 e(k) = e(k) - 2e(k - 1) + e(k - 2).
$$
In the equation, $\Delta^2 e(k)$ is the second-difference of the arc voltage deviation, which is measured at the k-th sampling time; $\Delta e(k)$ and $\Delta^2 e(k)$ represent the trends of $e(k)$ and $\Delta e(k)$, respectively; $V_f(k)$ is the welding speed; $V(k)$ is the stepping motor speed of the arc voltage distance-regulating system. $e(k)$ and $\Delta u(k)$ are the input and output of the k-th sampling moment of the expert PID controller respectively. This paper proposes the expert PID control rules of the arc voltage distance-regulating system, as shown in Table 1. $e(k)$ and $V_f(k)$ are the inputs of the speed controller of distance-regulation, and $V(k)$ is the output. This paper proposes the speed control rule of distance-regulation for the arc voltage distance-regulating system, as shown in Table 2.

![The expert PID control rules of the arc voltage distance-regulating system](image)

**Figure 3.** The arc voltage distance-regulating system

4. Simulation experiment

In order to test the performance of LMS filtering algorithm and expert PID control algorithm in the arc voltage distance-regulating system, this paper uses MATLAB to simulate and analyze these two algorithms, and the simulation results are shown in Fig.4 and Fig.5. In Fig.4, “input” is the 1000 arc voltage values collected by the arc voltage acquisition board; “output” is the output result obtained by the LMS filtering algorithm. It can be seen from Fig.4 that the LMS filtering algorithm can better remove the interference signal and fit the curve, which can effectively ensure that the signal amplitude is not weakened. In Fig.5, “out” is the output arc voltage value after adjusting by the arc voltage distance-regulating system; “set” is the optimal welding arc voltage; “actual” is the unregulated arc voltage value. It can be seen from Fig.5 that the arc voltage can be stabilized within the allowable error range through the adjustment of the expert PID controller and the speed controller of distance-regulation.

![The LMS filtering algorithm](image)

**Figure 4.** The LMS filtering algorithm

![The Expert controller](image)

**Figure 5.** The Expert controller

In order to further test the performance of the arc voltage distance-regulating system, this paper uses the arc voltage acquisition board to collect 1000 regulated arc voltage values and normal arc voltage values. The statistical results are shown in Fig. 6. According to the experimental results, the value of
welding arc voltage adjusted by the arc voltage distance-regulating system is closer to the optimal value of arc voltage than the normal value of arc voltage, and is stable within the allowable error range (18±0.8V). Therefore, the distance between the tungsten electrode and the weld bead is stable at (6±0.32)mm, meeting the working requirements of TIG welding robot.

![Graph showing arc voltage data](image)

**Figure 6.** The data of collected arc voltage

5. **Conclusion**

Through the adjustment of the arc voltage distance-regulating system, the arc voltage is kept within the accuracy range of ±5%, which satisfies the welding quality requirements of the welding robot.

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