The Control System of Friction Welding Machine for 5000kN Large Electrolytic Aluminum Prebaked Anode Conductor

Xiaolin Feng¹,²,³*, Haijie Mao¹,²,³, Chaorong Liu¹,²,³ and Manqiang Liu¹,²,³

¹College of Electrical and Information Engineering, Lanzhou University of Technology, Lanzhou, 730050, China
²Key Laboratory of Gansu Advanced Control for Industrial Processes, Lanzhou, 730050, China
³National Demonstration Center for Experimental Electrical and Control Engineering Education Lanzhou University of Technology, Lanzhou, 730050, China

*Corresponding author’s e-mail: splendor2003@lut.edu.cn

Abstract. A friction welding machine, which improves the connection performance of two different metals by generating heat of relative movement of friction, could increase the maximum contact area and lower energy and human labor consumption. The machine's control system reaches the manufacturing process's demands with its design and exerts its promising prospects.

1. Introduction

Traditional electrolytic aluminum prebaked anode conductor (from now on referred to as anode conductor), which is widely used in the aluminum production process, implements the jointing function between its aluminum guide rod part and cast steel claw part with the help of a composite explosive welding piece (as shown in Figure 1 and 2). The welding piece is made of steel at one end and aluminum at the other end, and workers are required to manually weld the aluminum part of it with an aluminum guide rod and the same as steel part with a cast steel claw.

Nevertheless, the technology mentioned above also exposes some disadvantages during the practice process, mainly focusing on considerable contact resistance, cumbersome processing, and easy cracking on the welded joint under high temperatures or other severe working conditions. Hence, it is in urgent need of improvement. [1,2]
Being an optimizing energy-saving, high-efficiency, precise, and environmentally friendly solid-phase connection technology, friction welding is selected as a proper way to realize jointing dissimilar metal. Under the action of constant or incremental pressure and torque, it uses the relative movement between the welding contact end to generate frictional heat on surfaces and its nearby areas. The heat of plastic deformation causes the temperature of the weldment's friction surface and its vicinity to rise to a temperature range close to but generally lower than the melting point. The material's deformation resistance reduced, the plasticity increase, and the oxide film at the interface broke. The material produces plastic deformation and flow, and the connection realizes through the diffusion and recrystallization metallurgical reaction on the interface\cite{3,4}.

In the industry, it is not hard to find dissimilar metal jointing with a relatively small sectional area. However, it is a challenge to weld an aluminum guide rod whose connecting area is $130 \text{ mm} \times 130 \text{ mm}$, and the cast steel claw is $165 \text{ mm} \times 210 \text{ mm}$.

2. The friction welding machine and its control process
The machine (as shown in Figure 3 and 4), which can generate the pressure of 5000kN to serve for friction welding process of anode conductor, consists of an axle box, upsetting device, cast steel claw fixture, aluminum guide rod fixture, feeding trolley, spindle motor, hydraulic system, and control system.
Figure 3. One side of design renderings of the friction welding machine.

Except for supporting the manual operation, the friction welding machine mainly uses its automatic way of manufacture, which is shown in Figure 5.

Figure 4. Another side of friction welding machine on the site.

3. The control network and control strategy

3.1. Control Structure Diagram

As shown in Figure 6, the control system uses the fieldbus Profibus DP to construct its network and uses the DP 485 relay as the star network hub to connect S7-400 PLC of Siemens, S120 transducer of Siemens (working with braking resistor), PVM58N absolute encoder of P+F (PEPPERL+FUCHS), and MP377 HMI of Siemens. The operating rate of 1.5Mbps ensures rapid signal transmission. An Advantech industrial computer collects operating data through the industrial fieldbus of Profinet. The transducer uses an incremental encoder to construct a speed closed-loop and ensure its accuracy, and the spindle motor and aluminum guide rods' operating positions are detected by an absolute encoder and a constant force opening meter individually. The PLC controls the soft starter, and it adopts the terminal control method and assists the corresponding safety design in the secondary circuit to improve its reliability. The PLC controls the aluminum guide rod fixture's movement speed and pressure of the hydraulic station by constructing an electro-hydraulic ratio closed loop to achieve timely and accurate control. During the friction process, the joint's temperature is detected in real-time by the infrared sensor and sent to the PLC controller. In the PLC control cabinet and power cabinet, the circuit breakers and AC contactors are designed with corresponding contact closure detection and alarm detection judgment during manufacturing time, which improves the reliability of system.
operation and the timely judgment of fault signals performance, which in turn, brings ease of system maintenance.

Figure 6. The structure diagram of the control system

3.2. Operation panel, HMI and industrial computer

The operation panel and HMI install on the flat face and vertical face of the control console individually. The most crucial operation actions, including manual operation and automatic start/stop switch control, carry out with help of operation panel (as shown in Figure 7). Except for showing the proximity switch signal on-site, HMI configures most of the analogy signals such as temperature, pressure, speed, position, electric currency, and also shows the set-point and remaining of each friction step time. Some auxiliary functions hide for a higher level operator to managing their manufacturing process.

The industrial computer collects and stores critical data on-site, which some from PLC through the fieldbus of Profinet and others from the transducer through the fieldbus of Profibus. All data are essential for analysing the friction process and reasoning out more optimized parameters for later use.

It ensures that the friction welding machine can manufacture anode conductor and support of researching the friction process of other large cross-section dissimilar metals.

Figure 7. Arrangement diagram of operation panel
3.3. Electro-hydraulic ratio closed loop control

To improve the quality of friction, the electro-hydraulic ratio closed-loop control method is considered a strategy for manufacturing anode conductor. A voltage of 0~10V of signal comes from PLC to control the servo valve in a specific hydraulic channel, and the value of voltage can decide the displacement and velocity of the aluminum guide rod fixture finally. Simultaneously, the feedback value of hydraulic pressure could be measured with a specific sensor and be sent to the PLC.

The PLC organizes the signals and carries out its control stratagem with the help of FB41 (Function block No.41 in the software of step7). Finally, the hydraulic pressure that acts on the aluminum guide rod fixture can be controlled within a specific set-point, thus controlling the friction between the cast steel claw and aluminum guide rod.

Large batches of manufactured anode conductors are placed under electrolyzers to test their power-saving performance. Comparing with traditional products (just like the test experiments done in the electrolysis workshop in Figure 8.), each anode conductor could reduce 8mV voltage on average [5].

3.4. Automatic phase control

The anode conductor demands the cast steel claw and aluminum guide rod be joined together through a friction process with a specific angle to fit the product process (as shown in Figure 9) [6]. The S120 transducer of Siemens is selected to satisfy the requirement because of its character of being a servo. A positioning switch and an incremental encoder are used to support the function, and the control system also selects an absolute encoder to record any movement trace of rotating cast steel claw. The absolute encoder possesses high-level resolutions that record a maximum of 16383 circles and 65535 pulses (divide 360° per circle) with each rotation. The absolute encoder also helps PLC decide a specific time point to enable automatic phase control, thus maintaining the quality of control effect.

The automatic phase control error could be calculated with the support of the absolute encoder. For example, the \( R_0 \) is the value that the absolute encoder sends to PLC and store in a word, and the error \( \Delta \alpha (°) \) could be a positive or negative number as:

\[
\Delta \alpha = \frac{65535}{360} \times (R_0-65535).
\]

\( (R_0>65535/2≈65534/2=32767, \Delta \alpha \) is a negative number) \)

\[
\Delta \alpha = \frac{65535}{360} \times (R_0-0) = \frac{65535}{360} \times R_0.
\]

\( (R_0<=65535/2≈65534/2=32767, \Delta \alpha \) is a positive number) \)

The action time of automatic phase control (\( T_s \)) could also be calculated by analysing data of the absolute encoder between the period of start and end point. Due to space limitations, only ten sets of data from field experiments list in Table 1.
Table 1. Automatic phase control error and time usage.

| R0   | Δα (°) | |Δα| (°) | Ts (ms) |
|------|--------|--------|-------|---------|
| 65434| -0.5548| 0.5548 | 4435  |
| 78   | 0.4285 | 0.4285 | 4758  |
| 65500| -0.1923| 0.1923 | 4268  |
| 43   | 0.2362 | 0.2362 | 4875  |
| 98   | 0.5383 | 0.5383 | 4657  |
| 65401| -0.7361| 0.7361 | 4609  |
| 65468| -0.3680| 0.3680 | 4657  |
| 65425| -0.6043| 0.6043 | 4359  |
| 65446| -0.4889| 0.4889 | 4209  |
| 65390| -0.7965| 0.7965 | 4365  |

4. Conclusions

Relying on rational and scientific design, the control system of friction welding machines could run safely within the demand process requirement. The energy-saving performance, lower 1° error, and 6s stop time of automatic phase control, all mean the technology possesses a promising future in Electrolytic aluminum and related industry.

Acknowledgments

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References

[1] Wang Xijing, Li Jingwei, Zhang Changqing, Zhang Yazhou, Sun Xuemin. Research on the mechanical properties and energy saving of electrolytic aluminum anode aluminum/steel friction welding joints [J]. Electric Welding Machine, 2014, 44(11): 56-60.

[2] Wenya Li, Feifan Wang. Modeling of continuous drive friction welding of mild steel[J]. Materials Science & Engineering A. 2011 (18).

[3] Choate W T, Green MUS J A S. Energy Requirements for Aluminium Production: Historical Perspective, Theoretical Limits and New Opportunities [R], Dept. of Energy, 2003.

[4] Wang Xijing, Shang Xianwei, Zhi Lili, Zhang Changqing. Microscopic analysis of large section cast aluminum-cast steel friction welded joints [J]. Transactions of the China Welding Institution. 2010(02).

[5] Guo Tui, Du Suigeng, Cui Anding. Research status and prospects of phase friction welding [J]. Machinery Manufacturing. 2014(03)