Development and Application of Hand-held Laser Welding System

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Abstract. In this paper, the composition, control mechanism and process control of control system of hand-held laser welding were studied. Based on PLC, galvanometer motor was better protected, control frequency of galvanometer was improved, the system expansibility was enhanced, and functions of continuous welding and continuous spot welding were realized. The application results indicated that the control system not only had the advantages of simple development, short development cycle and comprehensive monitoring, but also simplified the input and operation of parameters, reduced the workload of operators and reduced the operation difficulty of equipment to the greatest extent.

1. Introduction
The laser is mainly composed of three parts: laser working medium, excitation source and resonant cavity. Because of good directivity and monochromaticity of the laser, laser welding has advantages of fast, small deformation, pollution-free and non-contact, which is suitable for on-line processing of continuous metal materials. With the gradual improvement of laser power, the continuous development of miniaturized and integrated lasers and the continuous improvement of laser efficiency, laser welding technology, including plasma arc welding technology, laser and arc welding technology, double laser beam welding technology and hand-held laser welding technology, has been developed rapidly [1~3]. In particular, hand-held laser welding technology and equipment develop in the direction of high-power, miniaturization and integration, greatly reducing the cost, and have been applied more and more in the market.

2. Composition of Control System

2.1. System Composition
As shown in Fig.1, the control system of hand-held laser welding is mainly composed of PLC control system, host PC system, IPG laser and its control system, galvanometer motor and its servo controller, water-cooling system, gas-protection system and welding gun. The PLC control system adopted SIEMENS 1200 series is the control core of the whole system. The controls of laser power supply, water-cooling system, gas-protection system and sine wave and pulse wave of galvanometer motor were realized. And the communication and data exchange with host PC were realized. The host PC system
The adopted Siemens ktp700 touch screen is an important human-computer interface. It communicates with PLC through PROFINET, realizes parameter setting and control system monitoring. IPG laser is the carrier of laser production and its parameter is the most important process parameter of the system. Through the control of system, the output of laser power supply with different power, different frequency and different duty cycle can be realized. The galvanometer motor and its control system are used to produce large red light width, expand the width of welding and reduce the requirements of welding seam. Water-cooling system and gas-protection system are important guarantee to achieve good welding quality.

![Composition of control system.](image)

### 2.2. Advantages of Control System

Compared with the traditional board control, the PLC control system has the advantages of high reliability, strong anti-interference, simple programming, convenient use, strong applicability in harsh industrial environment and strong expansibility. The interruption program of Siemens 1200 PLC can achieve 1ms cycle output at the shortest time, which realize the highest 200 Hz frequency control of galvanometer control, and achieve high pulse output. By the PLC control, good process control and motion control are realized, high frequency control and pulse output of the system are come true, and a better effect of the control and protection of galvanometer motor are also achieved.

### 3. Working Mechanism of Hand-Held Laser Welding

#### 3.1. Composition of Galvanometer System

Galvanometer motor and its control system are an important part of hand-held laser welding, which can extend red light range of laser, plays an important role in welding irregular welds and increases the adaptability of welding.

Galvanometer system is a high-precision and high-speed servo control system, which is composed of servo controller and high-speed swing motor. Galvanometer lens consists of stator, rotor and detection sensor. Among them, the galvanometer is of moving coil type (rotor is coil), others are of moving magnetic type (rotor is magnetic core), and all galvanometer lenses are made of permanent magnets as magnetic core. The detection sensor is capacitive sensor, and the digital galvanometer is grating scale sensor. When the motor swings, the small changes in capacitance are detected, and then be changed into
an electrical signal, which is fed-back to the controller for closed-loop control. Actual deflection angle was measured by grating scale, and then be converted into electrical signal, which fed-back to the controller for closed-loop control. Because of the disadvantages of large volume, large moment of inertia and slow response, so the galvanometer of moving coil type is not used now. Because of the advantages of small volume and small inertia, the galvanometer of dynamic magnetic type has a good response performance, of which the hollow cylindrical core is tightly installed on the rotating shaft [4].

3.2. **Control Principle of Galvanometer**

By continuous and high-speed reciprocating oscillation of galvanometer motor, the red light produced by the laser power becomes a continuous red output. And its width is proportional to the swing angle of the galvanometer motor. Compared with triangle wave, trapezoid wave and rectangle wave, sine wave output is less impact and smoother, which is more suitable for the control and protection of galvanometer motor. Therefore, the control of galvanometer motor mostly adopts sine wave output mode [5]. As shown in Fig.2, the parameters (such as swing width and swing frequency) setting on the upper computer were performed analog-to-digital calculation and converted data by PLC, and finally were converted into digital signals, which were acceptable to the servo controller. The servo controller receives the sine wave signal and controls the galvanometer motor to swing at a certain angle and frequency. The whole process adopted closed-loop feedback control by actual speed, which feed-backed by galvanometer motor. The servo controller consists of five control circuits: position sensor, error amplifier, power amplifier, position discriminator and current integrator.

3.3. **A / D Calculation and Data Conversion**

The angle of galvanometer motor is directly proportional to the input voltage, the frequency is directly proportional to the frequency of voltage change, and the outputs based on PLC are all digital (analogs are also continuous digital outputs). Therefore, in order to obtain ideal outputs of sine wave control, it is necessary to carry out analog-to-digital calculation and data conversion for sine wave parameters. As shown in Formula 1, the output y of sine wave function is related to amplitude A, frequency ω and offset K.

\[ y = A \sin(\omega X + \Phi) + k \]  

The voltage output of the analog module from -10V to +10V corresponds to the digital quantity of -27648 to +27648, and the voltage input of 1mm red light width (single side width of 0.5mm) corresponds to 0.075v. Therefore, the relationship between the amplitude (voltage) and the digital quantity is as follows:

\[ A = 415 \times S \]  

One output point every 1ms will be generated by interrupt program of PLC, and 1000 output points will be generated every 1s. At the frequency of F, the output points of each waveform are 1000 / F. Therefore, for continuous sinusoidal waveform, each waveform is divided into several continuously changing output points, and the following relationship is obtained:

\[ \omega X = (2\pi f \times N) / 1000 \]
3.4. Laser Power Output

Laser power is the most basic parameter in this system. The stability and accuracy of laser power have a direct impact on the welding effect. Therefore, in the process of laser welding, it is important to monitor and control real-time laser power. The ultimate purpose of laser power monitoring is to control the laser power, so that the laser can operate well under a certain stable power. At present, the tail mirror sampling power test is used to monitor laser power commonly. The optical cavity mirror adopts a spherical mirror with stable low projection rate to sample the light projected by the spherical total mirror, and then focus the tiny leakage light through a focusing mirror, and the focal spot is received by a thin-film thermocouple infrared detector, which converts the different laser power output into different thermoelectric potential \([6\text{-}7]\).

The principle of laser power control is shown in Fig. 3, parameter of laser power is set on the upper computer, and then is converted into pump current (power) control signals via D / A module of PLC. The internal control loop of the laser power receives the control signal and converts them into corresponding power output. On the one hand, the internal detection system of the laser power compares the reflected power feedback signal with the control signal, and controls signal by inner close-loop output for ensuring the stability of the discharge current; On the other hand, according to the comparison between power feedback and power setting, the internal detection system of the laser power control the power output stably by external closed-loop. Therefore, the control system can achieve accuracy and stability of laser power output by double closed-loop control.

![Fig 3. Control Principle of Laser Power.](image)

Through selection of power mode and modulation of the laser power control circuit, laser power output has the following two ways mainly:

1) Continuous mode: this mode can produce continuous laser stably.

![Fig 4. Continuous Laser Waveform.](image)
(2) Pulse mode: This mode has a large power output, each pulse power is equal and adjustable. The frequency and duty cycle of pulse are adjustable, the adjusting range of frequency is 0-10kHz, the adjusting range of duty cycle is 0-100%, and the minimum adjusting accuracy is 0.01%. As shown in the Fig. 5 is the schematic diagram of pulse laser waveform.

![Pulse Laser Waveform](image)

**Fig 5. Pulse Laser Waveform.**

### 4. Principle of System Control Process and Application Conclusions

#### 4.1. Principle of System Control Process
As shown in Figure 5 is the schematic diagram of control process. Firstly, according to Welding parts of different materials and thicknesses, parameters were set or called relevant database on the host PC. Secondly, under the condition of ensuring the safety of personnel and equipment, welding parts started welding and be observed the weld quality. And finally welding quality were inspected after the completion of welding. The parameters that meet the process requirements will be saved for the next call. For unqualified products, the parameters will be reset and continued welding until qualified products obtained.

#### 4.2. Application Conclusions
The practical application results show that the control system based on PLC not only has characteristics of simple in development, short in development cycle, strong in controllability and expansibility, but also has advantages of complete in function, comprehensive in monitoring and simple in operation. The system improves the control frequency of galvanometer, realizes functions of continuous welding and spot welding of laser welding, simplifies the input and operation of parameters, reduces the workload of operators, and reduces the operation difficulty of equipment to the greatest extent.
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References

[1] Casalino G. Statistical analysis of MIG-laser CO₂ hybrid welding of Al- Mg alloy [J]. Journal of Materials Processing Technology, 2007, (191):106-110.

[2] Chen Y B, Lei Z L, Li L Q, et al. Experimental study on welding characteristics of CO₂ laser TIG hybrid welding process[J]. Science and Technology of Welding and Joining, 2006, 11(4): 403-411.

[3] Gao M, Zeng X Y and Hu Q W. Effects of welding parameters on melting energy of CO₂ laser-GMA hybrid welding[J]. Science and Technology of Welding and Joining, 2006, 11(5): 517-522.

[4] Quintino L, Costa A, Miranda R, et al. Welding with high power fiber lasers-A preliminary study[J]. Materials and Design, 2007, (28): 1231-1237.

[5] Maffini A, Moser L, Marot L, et al. In situ cleaning of diagnostic first mirrors: an experimental comparison between plasma and laser cleaning in ITER-relevant conditions[J]. Nuclear Fusion, 2017, 57(4): 046014.

[6] Qiang Wu, Jinke Gong, Genyu Chen, et al. Research on laser welding of vehicle body[J]. Optics & Laser Technology, 2007, (6): 1-7.

[7] Xilin W, Han W, Xiaoran X, et al. A new method to remove the aging RTV coatings on glass insulators[C]//Dielectrics (ICD), 2016 IEEE International Conference on. IEEE, 2016, 2:709-711.