Research on Cathode Heating Power Supply for Electron Beam Equipment

Xiaoda Liu

[1]Electrical engineering and its automation, North China University of Technology, Beijing, China

[a]15646599116@163.com

Abstract

With the development of electron beam welding technology, there are higher requirements for the output stability and universality of cathode heating power supplies. To meet the demand for power supply of electron beam equipment with different frequencies in the market, this project designs a cathode heating power supply with switchable output frequency. The cathode heating power supply is composed of STM32F407 microcontroller, full bridge inverter circuit, sampling circuit, 7-inch touch screen, etc. Firstly, the microcontroller ADC collects feedback signals, and after data processing and digital PID operation, outputs PWM signals with different duty ratios. After being amplified by the driving circuit, the power device is driven to change the output voltage and current. At the same time, the 7-inch touch screen can display real-time output voltage, current, frequency and other information, and can complete parameter settings through the touch screen. The final experiment shows that the designed cathode heating power supply of the electron beam equipment can achieve stable control of different frequency power supplies, which better meets the project indicators.

Keywords

Electron beam; Catode heating; STM32.

1. INTRODUCTION

Electron beam welding machines are usually composed of high-voltage power supply systems, control systems, vacuum systems, workbenches, and auxiliary devices. Electron beam welding technology has the characteristics of low heat input, small workpiece deformation, no welding rod, high work efficiency, and difficulty in oxidation. It is widely used in industries such as national defense, aerospace, and welding of precision electronic instruments.

The cathode heating power supply is used as a part of the high-voltage power supply system in practical applications, mainly for heating the cathode to overflow electrons. With the improvement of electron beam welding technology, the stability and current ripple requirements of cathode heating power supply output are becoming more stringent [2].

The existing cathode heating power supplies in the domestic market have three outputs: power frequency 50Hz, intermediate frequency 1kHz, and high-frequency 20kHz. This project designs a cathode heating power supply with switchable output frequency to meet the needs of all electron beam equipment in the market and improve the universality of the cathode heating power supply.

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2. HARDWARE DESIGN OF CATHODE HEATING POWER SUPPLY

2.1. Main structure of power supply

This design converts a 48V DC power supply into a single-phase AC output through an inverter circuit. The AC output is sampled and transmitted to the AD sampling port of the CPU. After processing the signal by the CPU, PWM signal controls the AC output of the inverter circuit.

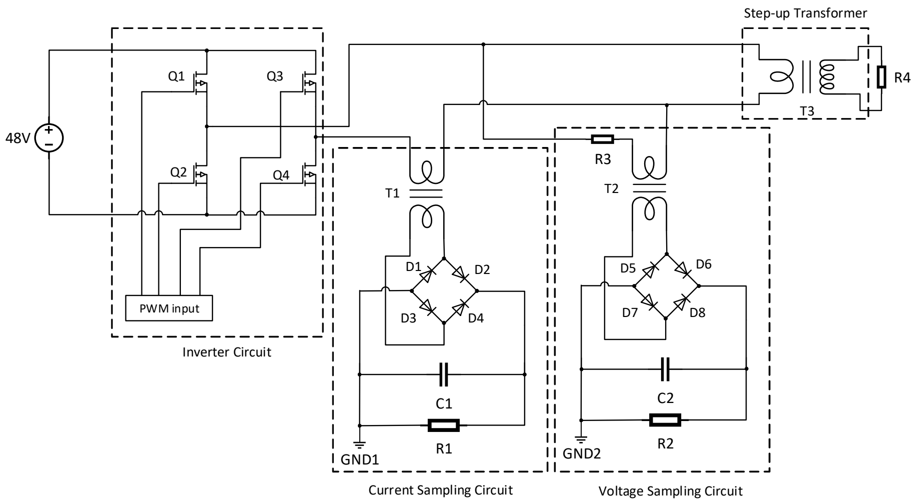

Figure 1. Main Circuit of Cathode Heating Power Supply

2.2. Microcontroller minimum system

This design uses the STM32F407 chip as the CPU, which is a high-performance microprocessor based on the Cortex-M4 core[3]. The main frequency pass can reach 168MHz. Use the LM1117-3.3 chip to stabilize the 5V power supply provided to 3.3V to power the CPU. The CPU achieves functions such as generating PWM pulses, collecting output voltage and current, digital PID control, and communicating with the serial port screen.

2.3. Auxiliary power circuit

The VIPER22A chip integrates a dedicated current type PWM controller and a high-voltage power MOSFET, and the breakdown voltage between the internal MOSFET drain and source can reach 730V [4]. As shown in Figure 2, the VIPER22A chip is used to construct a Buck circuit, reducing the 48V DC power supply to 15V and supplying power to other devices in the circuit.

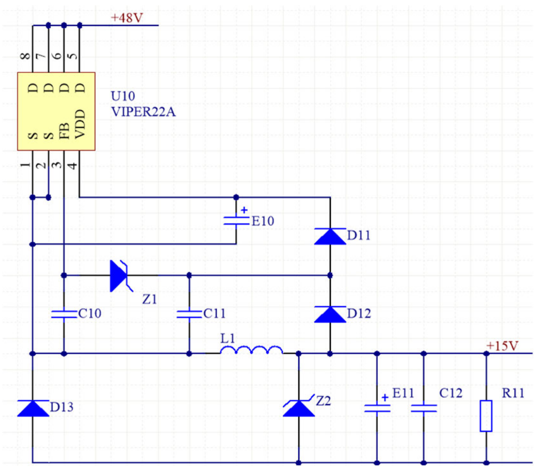

Figure 2. Step-down Chopper Circuit

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2.4. Drive circuit

MOSFET is suitable for electronic circuits with high switching frequency but low power level. MOSFET is chosen as the power device in this design. The capacitance between the MOSFET gate and source electrodes is relatively large, and low resistance output is required to quickly establish the driving voltage when turned on.

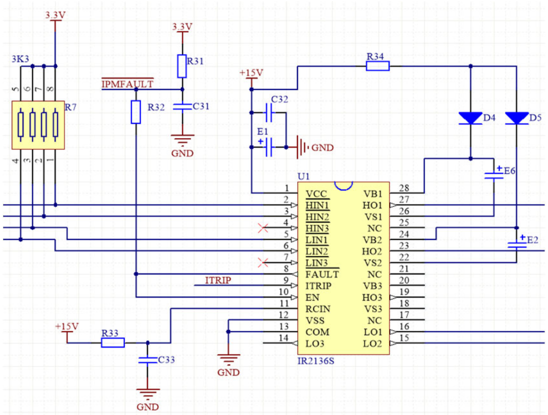

Figure3. Drive Circuit

A suitable driving circuit can make the power device work in an ideal state, reduce the heat loss of the power device, and extend the service life of the entire equipment. After comprehensive consideration, the three-phase bootstrap IR2136S chip is selected as the driving chip of this circuit, and an overcurrent protection circuit is designed.

3. SOFTWARE DESIGN OF CATHODE HEATING POWER SUPPLY

3.1. Software Control Block Diagram

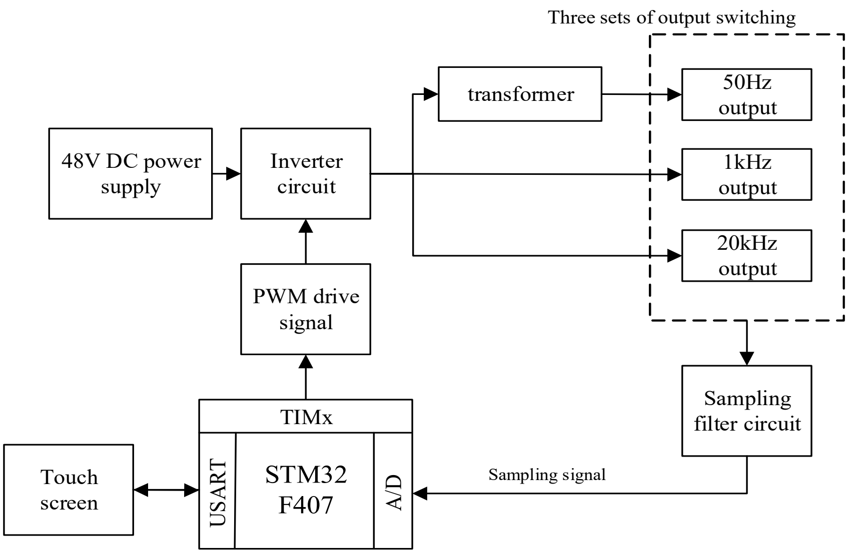

Figure 4. Software Control Block Diagram of Cathode Heating Power Supply

The CPU controls the output of the inverter circuit by outputting PWM pulses, samples and filters the power output, and then transfers it to the ADC. The CPU performs digital PID calculations, adjusts the PWM pulses based on the calculation results, and changes the power output. The serial interface screen can display real-time output voltage, current, and fault information, and complete the output voltage and current setting function through the operation screen.

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3.2. SPWM modulation principle

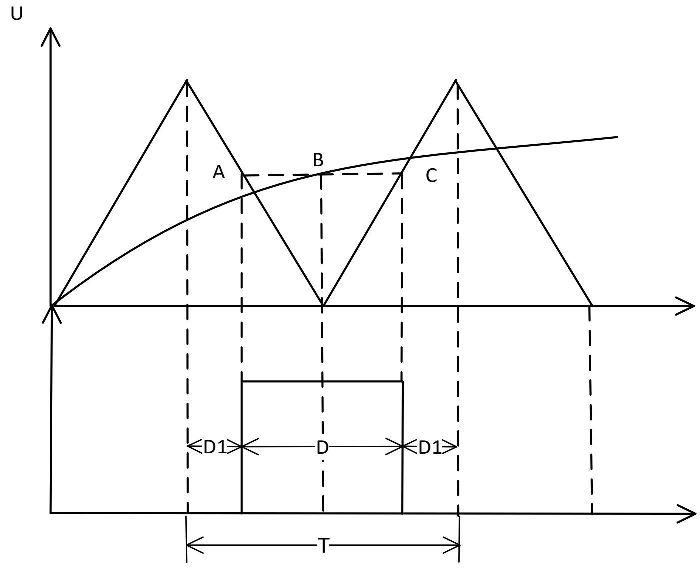

Figure 5. SPWM modulation principle

According to the principle of area equivalence principle, regular sampling method is used for modulation, triangle wave is used as carrier wave, sine wave is used as modulation wave, and SPWM modulation is used when 50Hz power frequency power supply is output[6].
Sinusoidal modulation wave:

$$u_r = asin\omega_r t \tag{1}$$

From the geometric relationship, it can be seen that:

$$\frac{1+asin\omega_r t_D}{\sigma/2} = \frac{2}{T/2} \tag{2}$$

It can be concluded that:

$$D = \frac{T}{2}(1 + asin\omega_r t_B) \tag{3}$$

3.3. Digital PID Control Program Design

After entering the interrupt program, the sampling circuit collects the sampling signal and sends it to the CPU. After receiving the sampling signal, the CPU reads and processes the signal, calculates the given value and the sampling value to obtain the PID control quantity. Then, the PID calculation process is started in the interrupt program, and the PWM pulse duty cycle output by the CPU is controlled by the PID calculation result. The obtained PWM pulse is output to change the output current of the inverter circuit, After PWM pulse output, exit the interrupt and wait for the next overflow interrupt [7]. The entire PID control program diagram is shown in Figure 6:

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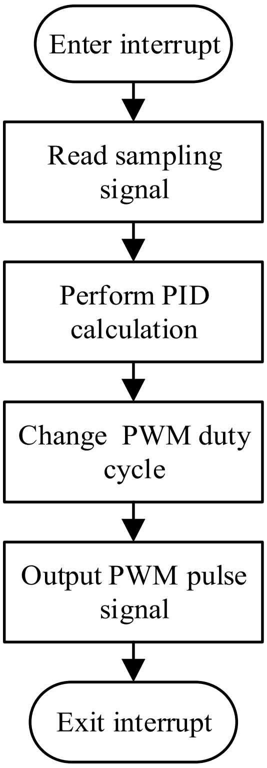
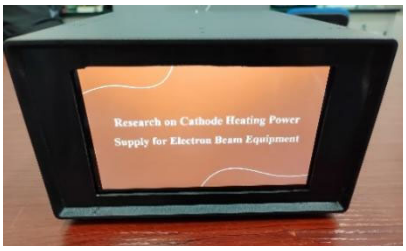


Figure 6. PID Adjustment Program

4. EXPERIMENTAL RESULTS AND ANALYSIS

4.1. Power supply prototype

The structure design of the cathode heating power supply was carried out using a cold rolled sheet iron box, and the prototype was completed.



(a) Cathode heating power supply main interface

(b) 20kHz output interface

(c) 1kHz output interface

(d) 50Hz output interface

Figure 7. Cathode heating power supply prototype

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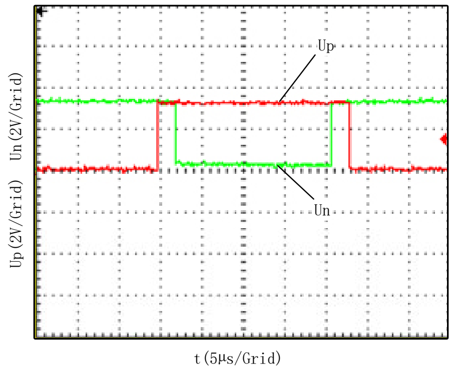
4.2. Different frequency power supply experiments



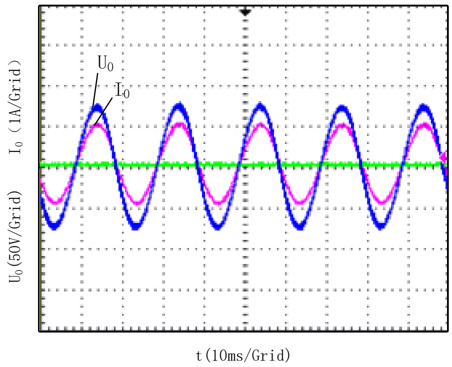


Figure 8. PWM Waveform **Figure 9.** 50Hz Power Supply Output Waveform

Figure 8 shows two complementary deadband waveforms output by TIM1, with a PWM cycle of 20kHz and a deadband time 2μs.

Figure 9 shows the waveform of the output voltage and current of a 50Hz power supply under load, using voltage closed-loop control to output a standard single-phase sinusoidal AC current signal in steady-state.

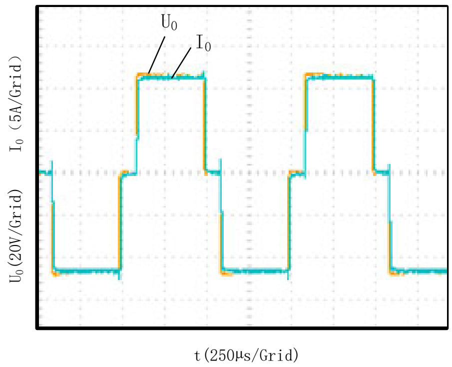


Figure 10. 1kHz Power Supply Output Waveform

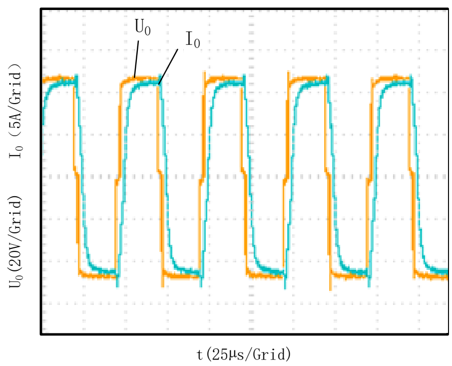


Figure 11. 20kHz Power Supply Output Waveform

Figure 10 shows band 4 Ω under pure resistive load, the output voltage and current waveforms of the 1kHz power supply are basically consistent with the output voltage and current waveforms.

Figure 11 shows Band 4 Ω under pure resistive load, the output voltage and current waveforms of the 20kHz power supply are approximately the same as the output voltage and current waveforms.

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5. CONCLUSION

Through the above research, this design has achieved the following requirements:

(1) Design a schematic diagram, draw a PCB board, and achieve three sets of switchable outputs;

(2) Configure a serial port screen to display the output status of the power supply and set the power output;

(3) Using PID closed-loop control to maintain stable output voltage and current.

Through experimental verification, it can be concluded that the stable output of three sets of power supplies has been achieved, and the display and touch functions of the screen are normal.

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