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Research on High Voltage Power Supply for High Power Electron Beam Equipment

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Abstract

In response to the power supply requirements of high-power electron beam equipment, a 90kV/15kW intelligent fully digital controlled high-frequency high-voltage high-power electron beam power supply is designed by studying the existing power supply systems of high-power electron beam welding machines at home and abroad, and combining the embedded and real-time control technology of STM32MP157, power electronics, and the characteristics of high-voltage power supply for high-power electron beam equipment. Finally, through theoretical calculations and scheme design, a prototype of a high-power electron beam equipment high-voltage power supply is built. The experiment shows that this power supply can control the stable output of three sets of power supplies, and the screen can also display real-time information such as the power supply output, current, switch status, and faults, effectively completing the research content of this topic.

Keywords

Electron beam; STM32MP157; High voltage; High-power.

1. INTRODUCTION

Electron beam equipment is widely used in welding fields such as aerospace and automotive manufacturing. The high voltage output quality and stability of the high-voltage power supply of electron beam equipment directly affect the quality of electron beam welding[6]. Nowadays, with the increasing application range of electron beam welding, designing a high-frequency high-voltage DC switching power supply for high-power electron beam equipment can better meet the different application scenarios of electron beam equipment, Meet the needs of industrial production[2].

To achieve a fully digital intelligent high-voltage power supply, this question selects STM32MP157 with dual core heterogeneity as the control chip, aiming to develop a 90kV high-power electron beam equipment power supply that integrates Linux system and real-time control system.

2. HARDWARE DESIGN

The entire power supply hardware consists of three-phase rectification, inverter, filtering module, fault protection circuit, control system, voltage doubling rectification circuit, precision resistance tower sampling circuit, and human-machine interaction. The three-phase mains power is supplied to the electron gun through power electronics and high-voltage conversion.

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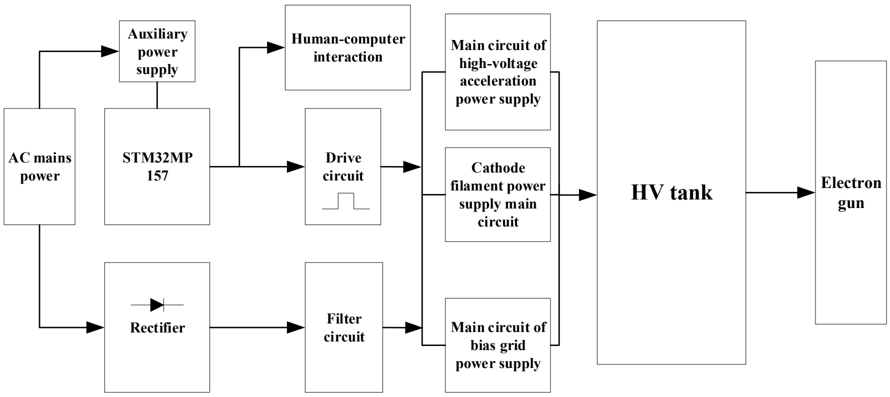

Figure 1. Hardware System Block Diagram

2.1. Microcontroller minimum system

The microcontroller minimum system is the core of realizing this high-power electron beam high-voltage power supply. The minimum system consists of a power supply circuit, crystal oscillator circuit, CPU, etc. The CPU power supply uses a synchronous voltage regulator EA3059QDR chip, with a high-precision crystal oscillator of24MHz as the external clock source. This selection tool has dual core isomerism of 800MHz main frequency Cortex-A7 and 209MHz main frequency Cortex-M4 cores, and 3DGPUSTM32MP157DDA1 as the control core. Realize the control of this power supply and the application of Linux system, and develop communication and human-machine interface of this system through CPU.

2.2. LC series resonant circuit

Introducing LC series resonance in the main circuit of the cathode filament power supply reduces the voltage to zero before the MOSFET is turned on. Reduce the current to zero before turning off the MOSFET, limit the power loss during the switching process, improve power efficiency, and reduce ripple, achieving zero voltage and zero current opening and zero voltage and zero current closing of the MOSFET with the same bridge arm in the cathode heating power circuit[3]. That is, through soft switching technology $f_s < \frac{1}{2} f_r$ to achieve the regulation of cathode heating power supply in the case of f_s is the switching frequency of the MOSFET, f_r the resonant frequency of the LC series resonant circuit.

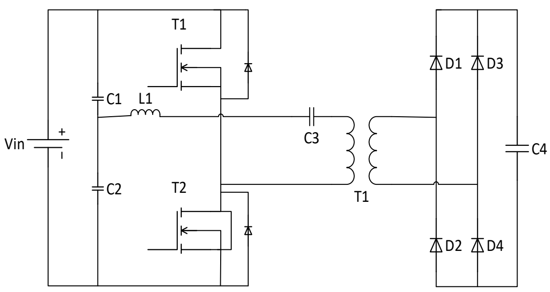

Figure 2. Series Resonance Circuit

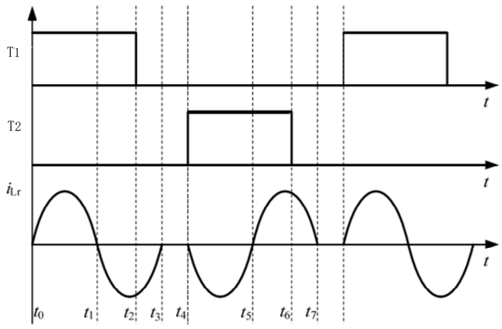

Figure 3. Working Waveform in DCM Mode

Resonant frequency:

$$\omega_0 = \frac{1}{\sqrt{L_1 C_3}} \tag{1}$$

Quality factor:

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$$Q_0 = \frac{\omega_0 L}{r} = \frac{1}{r}\sqrt{\frac{L_1}{C_3}} \tag{2}$$

When in$f_s < \frac{1}{2} f_r$ in this case, the LC series resonant circuit is in intermittent mode (DCM), T_1 and T_2 the driving signals of the two MOSFETs on the corresponding bridge arm are respectively, i_Lr to flow the current through the resonant inductor, the working mode of LC series resonance is divided into four working stages:

(1) t_0 moments, T_1 tube zero current conduction, followed by L_1 and C_3 resonance occurs, i_{Lr} starting to increase, t_1 the current flowing through the resonant inductor at all times i_{Lr} resonance to 0;

(2) t_1~ t_2 at any moment, the current undergoes reverse resonance,and t_2 moments the tube T_1 shutdown;

(3) t_2~ t_3 moments, tueb T_1 zero voltage shutdown, the anti parallel diode of the tube T_1 continues to resonate and continue to flow; stay t_3 the current flowing through the resonant inductor at all times i_{Lr} resonance to 0;

(4) t_3~ t_4 at all times, the current flowing through the resonant inductor i_{Lr} is 0, T_1 and T_2 all are turned off without resonance until the next cycle.

2.3. Voltage doubling rectifier circuit

The voltage doubling circuit is an important part of this power supply[4]. As the two secondary windings of the high-voltage transformer used in this question are respectively boosted to 22.5kV, the high-power electron beam equipment designed in this question can achieve a high voltage output of up to 90kV. Therefore, the high-voltage power supply uses the secondary winding to output twice the voltage in series to achieve a high-frequency high-voltage output of 90kV. The voltage doubling rectification circuit design is shown in Figure 4.

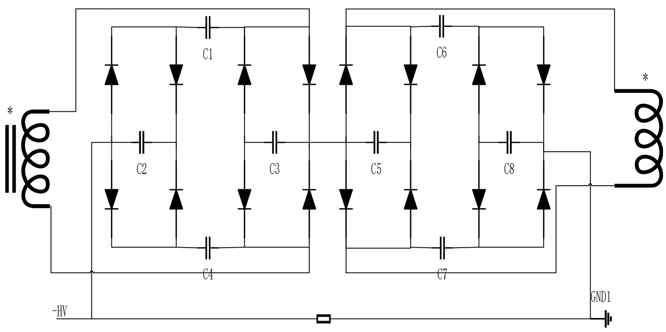

Figure 4. Double voltage circuit

Ripple voltage:

$$\Delta u = \frac{nDI_L}{2Cf} \tag{2}$$

Voltage drop:

$$\Delta U = \frac{DI_L}{Cf}\left(\frac{1}{3}n + \frac{1}{8}n^2 + \frac{1}{24}n^3\right) \tag{3}$$

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The maximum PWM pulse duty cycle is 50%, the load current is 167mA, the ripple coefficient is less than 0.05%, the frequency is 20kHz, and the selected capacitor is not less than 0.00125μF, thus to choose 2μF capacitor for this question.

2.4. Power supply structure design

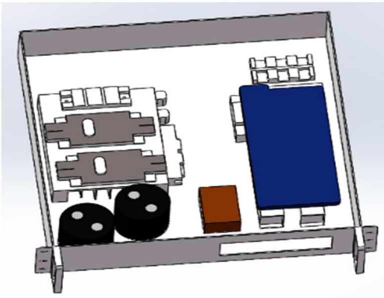

Figure 5. Control Cabinet Structure

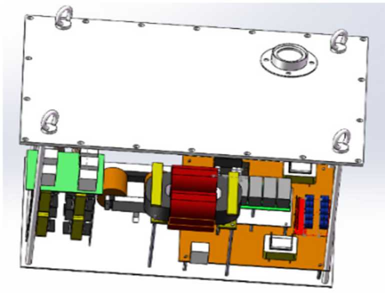

Figure 6. High Pressure Fuel Tank Structure

The control cabinet is mainly composed of high voltage and large capacity electrolytic capacitor, high-power IPM module, air-cooled aluminum radiator, cooling fan, switching power module, contactor, control board, drive board and inductor, which is used to complete the whole power system.

The internal structure of the fuel tank is an important part of this power supply design, which is used to convert the inverter output AC low voltage into stable DC high voltage. The oil tank mainly includes high-voltage transformers, cathode filament transformers, bias grid transformers, high-voltage rectifier boards, double voltage plates, precision sampling resistance boards, capacitor boards, and bakelite. The oil tank is installed in a hanging type while ensuring high-voltage insulation.

3. SOFTWARE DESIGN

This project takes the high-performance STM32MP157DDA1 with dual core heterogeneity as the core design program, which includes real-time control of M4 kernel and Linux system application of A7 kernel, to design an intelligent fully digital high-voltage power supply.

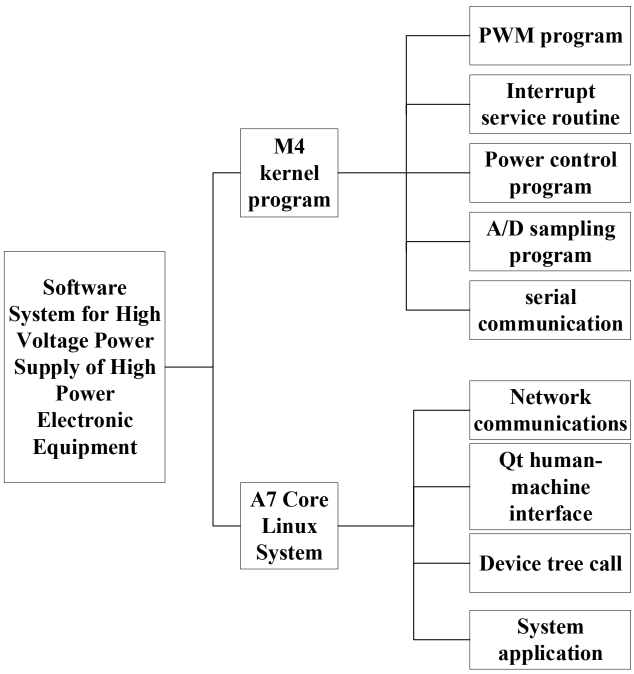

Figure 7. Software Design Block Diagram

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3.1. Power Control Program Design

The M4 kernel program of STM32MP157DDA1 is used to complete real-time control of the power supply. The control principle is shown in Figure 8[1]. After the initialization of the M4 kernel is completed, fault handling and interrupt service are completed. During the interrupt service, PWM adjustment is achieved through a 16 bit resolution ADC sampling and PI control algorithm, achieving closed-loop adjustment of the entire power output.

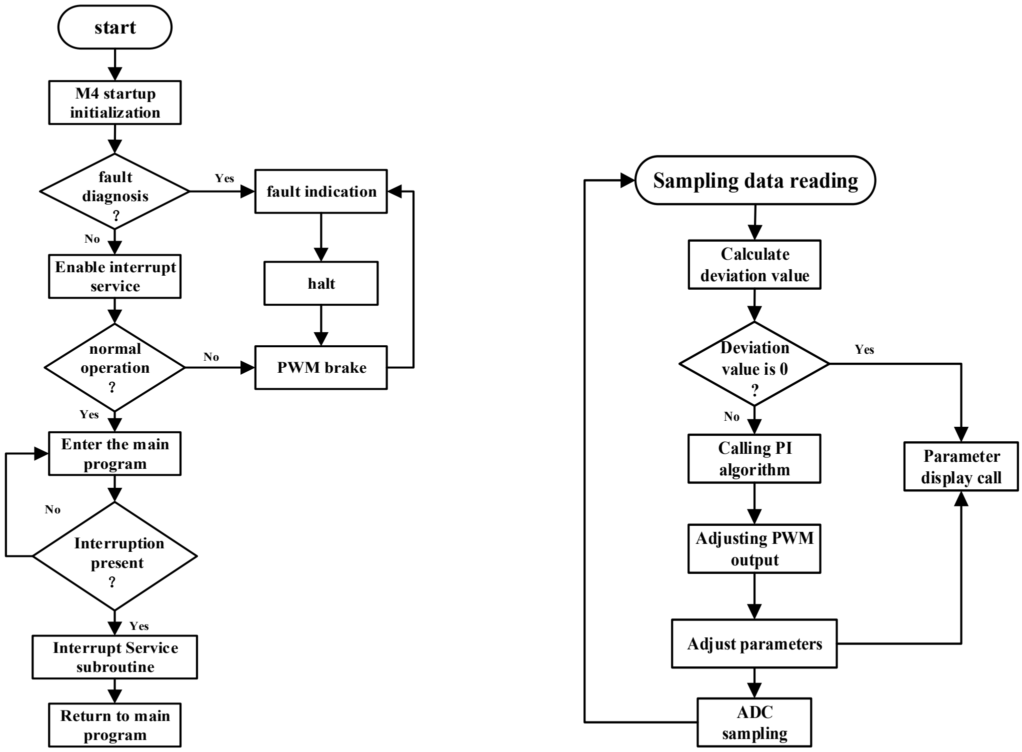

Figure 8. Power Control Program Block Diagram

3.2. Linux application design

A7 kernel development is a Linux system application based on the Ubantu environment, mainly including communication protocol programming, trusted firmware TF-A, Uboot, and device tree transplantation and compilation[5]. Linux system applications can achieve gigabit network communication, drive a 7.0-inch RGB LCD screen, upgrade system applications, and apply power at the system level.

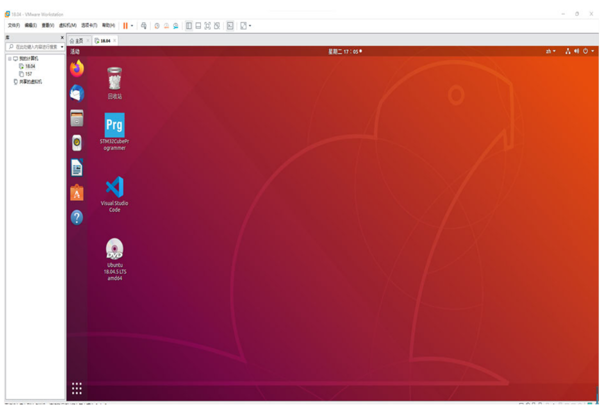

Figure 9. Ubuntu System Interface

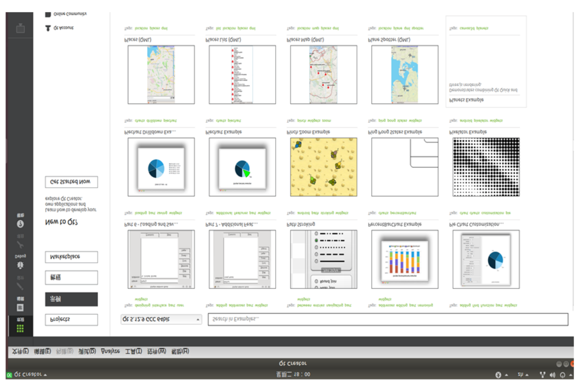

Figure 10. Qt Creator Interface

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As a digital high-voltage power supply with embedded system applications, the Qt display interface plays an irreplaceable role in monitoring and controlling the power supply. In this question, a 7-inch RGB resistive touch screen is selected as the human-machine interaction medium to drive the RGB LCD display screen. After that, the initialization interface, menu display page, personal information page, power operation indicator interface, and power parameter monitoring interface are designed using Qt Creator software.

4. EXPERIMENTAL RESULTS AND ANALYSIS

The high-voltage power supply hardware platform of high-power electron beam equipment consists of three parts: power cabinet, control cabinet, and high-voltage oil tank, as shown in the figure.

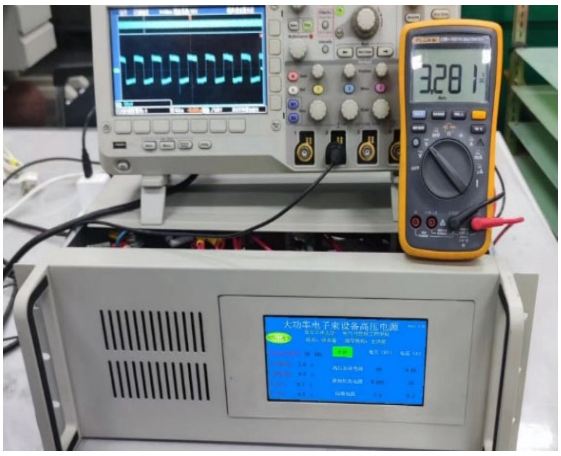

Figure 11. Experimental Platform Diagram

4.1. Human machine interface testing

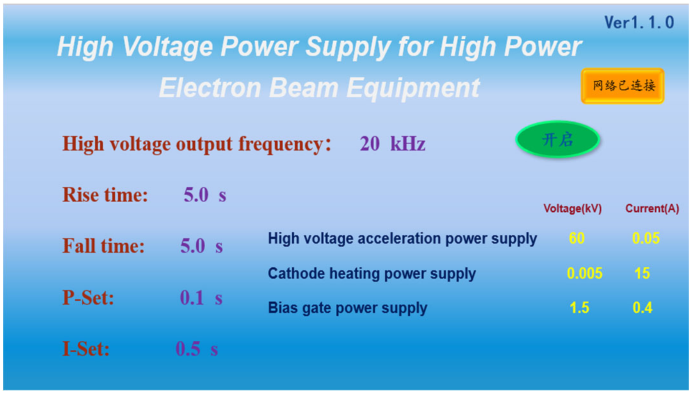

Figure 12. Qt human-machine interface

As shown in Figure 12, the information display of the project was achieved through a 7.0 inch high-resolution resistive RGB LCD touch screen. During the operation of the power supply, the parameters of the high-power electron beam equipment high-voltage power supply were read and written through data layer calling, completing parameter monitoring and modification of the power supply.

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4.2. Cathode filament power supply experiment

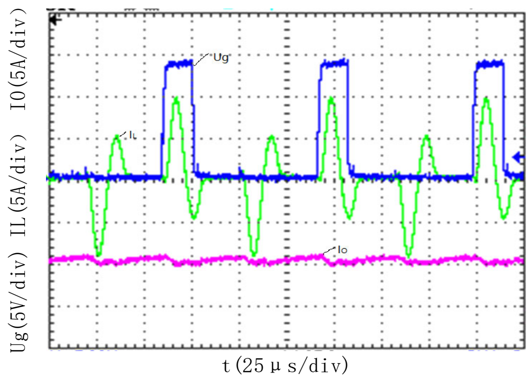

Figure 13. Output Waveform of 10A Filament

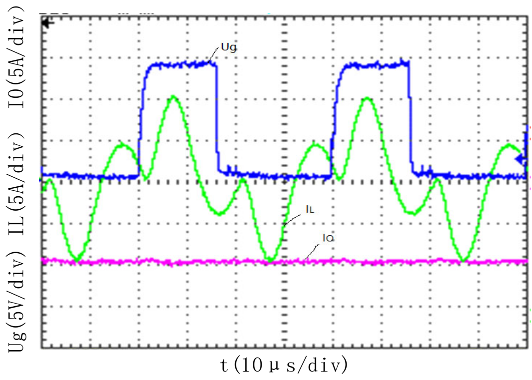

Figure 14. Output Waveform of 20A Filament

As shown in Figures 13 and 14, the cathode heating power supply of high-power electron beam equipment generates MOSFET tube driving waveforms and corresponding MOSFET tube voltage drop waveforms, as well as the waveform of the current flowing through the resonant inductor and filament current waveforms under three different output currents of 10A and 20A. From the figure, it can be seen that as the switching frequency approaches half of the series resonant frequency, the cathode filament current tends to a continuous state, achieving functional testing of the filament power supply soft switch.

4.3. Bias gate power supply experiment

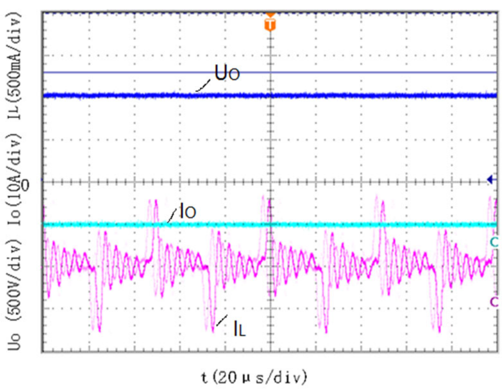

Figure 15. Bias Gate 1000V Output Waveform

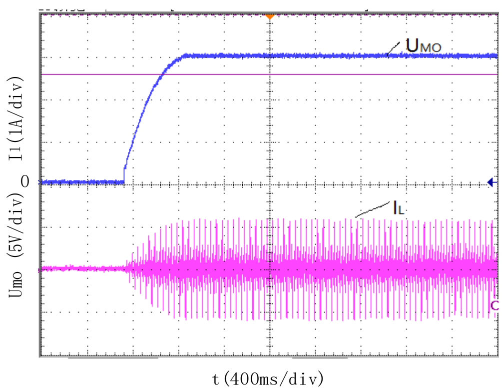

Figure 16. Bias Gate 1500V Start Waveform

As shown in Figures 15 and 16, the waveform of the bias gate power supply for high-power electron beam equipment is at 1000V and the startup waveform is at 1500V. From the waveform, it can be seen that the voltage and current startup and output of the bias gate power supply are relatively stable, and the bias gate power supply can operate stably in high-voltage environments.

5. CONCLUSION AND OUTLOOK

This article mainly studies the high-voltage power supply system for high-power electron beam equipment based on STM32MP157 control. The preliminary design of the high-voltage power supply for high-power electron beam equipment in the laboratory stage was completed through hardware circuit design, PCB circuit welding debugging, software programming, structural design, and no-load experimental testing.In the future, high-speed wireless network modules and 5G communication modules can be designed to achieve cloud based big data monitoring and control of this power supply, further develop the embedded application layer

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of this power supply, optimize and improve human-machine interaction display, and complete the development of MIPI LCD display interface, improving the resolution and response speed of the human-machine interface.

REFERENCES

[1] Li Zhengxi, Wang Zeting, Fan Shengwen Development of High Frequency and High Voltage Electron Beam Welding Machine Power Supply [J] Journal of North University of Technology, 2010,22 (03): 16-18+45.

[2] Fan Shengwen, Wang Zeting, Li Zhengxi Development of High Voltage Power Supply for Electron Beam Welding Machine Based on Phase Shifting Full Bridge [J] Power Electronics Technology, 2010, 44 (12): 62-64.

[3] Zhang Hongyin Research and Design of High Voltage Power Supply for Electron Beam Welding Machine [D]. Northern University of Technology, 2015.

[4] Dai Wei Development of a High Frequency and High Voltage DC Power Supply for a 90kV Electron Microscope [D]. North University of Technology, 2018.

[5] Zhang Guozhou Design and Development of Data Acquisition System Based on ARM Embedded [D]. Chongqing University, 2016.

[6] David Duan Development of 90 kV/15 kW High Voltage DC Power Supply for Electron Beam Welding [J] Journal of Bengbu University, 2018,7 (05): 63-66.