Research of pulsed Xenon lamp power supply based on STM32

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Abstract: Novel coronavirus pneumonia affects the health of people all over the world. In this study, UV pulse high-light sterilization technology was used to combat coronavirus. The light source of the ultraviolet pulsed high-light disinfection robot is a kind of high-brightness flash light source using pulsed xenon lamps as the output load. This paper developed a pulsed xenon lamp power supply with a high-voltage pulse synchronous trigger function, a DC charging voltage of 1kV-3kV, an output pulse current range of 1kA-3kA, and a pulse width of 50µS for a pulsed xenon lamp with a 196mm×Φ10mm and a resistivity of 12Ω·A¹/². This paper presented the experimental results of charging voltage of 1kV, output pulse current peak value of 1kA, and pulse width of 50µS. The power supply design was based on the phase-shifting voltage regulation mode of UC3825 control power MOS tube, through the sampling isolation module and the closed-loop feedback formed by STM32 control, the energy storage capacitor was linearly charged through the DC voltage sampling and voltage regulation control module; the trigger pulse signal was generated by the SCR switch, and the xenon lamp was turned on and emits flash light after the pulse transformer was boosted. The sample test results verified the feasibility of the power supply design principles and technical solutions.

1. Introduction

The sudden outbreak of new coronary pneumonia [¹] in 2020 has undoubtedly become the most concerned event. Now studies have shown that viruses are sensitive to heat, and it can be killed in a short time with 75% alcohol, ultraviolet radiation [²], etc. Ultraviolet disinfection technology will produce ozone, and continuous exposure will cause damage to human skin and eyes.

The pulsed light sterilization technology has no harmful residues, and the pulsed light has high energy intensity, and the disinfection time is very short. The pulsed light sterilization has the advantages of environmental protection, convenience and high efficiency [³], and sterilization can be completed in as little as 5 minutes. Therefore, our university teachers and medical equipment companies jointly developed a pulsed light sterilization robot to solve the public disinfection problem. This equipment can be widely used in places where people gather in hospitals, nursing homes, shopping malls, movie theaters, etc., which are likely to cause public health. The pulsed xenon lamp power supply studied by Shao Ruoyan [⁴] et al was used in high-speed photography. The pulsed xenon
The pulse xenon lamp power supply studied in this paper was mainly used for disinfection and sterilization in various hospitals and other public places. A pulse xenon lamp discharge device with good performance can excite the xenon lamp to obtain stable illuminance, and it can accurately control the discharge process of the xenon lamp with a delay at the same time, which is beneficial to the time-related operation of the high-power laser system. This paper mainly adopted capacitive energy storage and high-voltage synchronous trigger technology, realizes pulse formation network based on actual theory, analyzes pulse xenon lamp discharge parameters, synchronous trigger circuit, PWM phase shift control circuit, DC voltage sampling and voltage regulation control circuit. The pulsed xenon lamp driving power supply designed in this paper meets the performance requirements of the ultraviolet pulse disinfection robot through the sample test, and the power supply system could run stably and reliably.

2. System composition and working principle

2.1. Basic composition

The high-reliability xenon lamp power supply system of UV pulse disinfection robot described in this paper was composed of high-voltage pulse trigger unit, xenon lamp charging and discharging circuits. The system structure was shown in figure 1. The high-voltage pulse trigger circuit mainly adopted the technology method combining analog circuit, driving circuit and high frequency power MOS switch circuit to realize the design of the high-voltage pulse synchronous trigger unit in the pulse xenon lamp power system. It mainly includes three parts, respectively trigger circuit, drive circuit, and high voltage pulse forming circuit. The xenon lamp charging and discharging circuit mainly adopted the technical route combining high-voltage power supply and pulse forming network to realize the functions of charging, discharging and controlling the xenon lamp in the power system. It included three parts, namely the main charging circuit, energy storage circuit, and discharging network.

2.2. Working principle

Xenon lamp charging and discharging circuits included high-voltage charging power supply, PWM control circuit, STM32 closed-loop voltage control circuit and voltage sampling circuit to form the high-voltage DC charging power supply; energy storage capacitors and xenon lamps formed the xenon lamp discharge circuit.

The working process: the human sets the output voltage of the high-voltage DC charging power supply and the disinfection time on the touch screen of the UV pulsed high light disinfection robot at first, then the energy storage capacitor will be linearly charged through the STM32 control voltage regulating module. When the trigger pulse of the SCR is input, the high voltage pulse trigger unit will generate a high-voltage pulse of more than 20kV. The high-voltage pulse signal will ionize the gas in the xenon lamp to form a discharge channel, and the energy storage capacitor will light up the xenon lamp through the transmission cable, and the pulsed xenon lamp will continuously emit strong light and start disinfection within the set time.

![Figure 1. Structure of pulsed xenon flash lamp power supply system.](image)

3. Design of the hardware circuit

3.1. Electrical characteristic parameters of pulsed xenon lamp

The interior of the pulsed xenon lamp is the inert gas xenon. The luminescence of the pulsed xenon
lamp is an unsteady gas discharge process, which works in the form of pulsed discharge and can generate very large instantaneous power in a short time and emit strong light. The impedance of the xenon lamp is a function of time and current density. The impedance characteristic of the xenon lamp determines the efficiency of energy transfer from the storage capacitor to the xenon lamp. As the arc grows, the lamp resistance is a decreasing function of time. When the arc is stable, the relationship between the current and voltage of the xenon lamp is \( V = K_0 i^{0.5} \), where \( K_0 \) is the impedance characteristic of a specific xenon lamp, and its value depends on the type of gas, the gas pressure and the size of the lamp. According to formula \( 6 \), it can be obtained
\[
P = 1.27 \left( \frac{P}{450} \right)^{\frac{1}{3}} \frac{l}{d}
\]
(1)
\( P \) is the pressure of the xenon lamp; \( l \) is the distance between the two electrodes of the xenon lamp; \( d \) is the inner diameter of the xenon lamp in the formula. Under the condition of high current discharge, the xenon lamp tube is filled with plasma, and the resistance of the xenon lamp is as follows \( 6 \).
\[
R(t) = K_0 \left( L^2 \right)
\]
(2)

The damping factor \( \alpha \) of the current pulse shape determines the size, pulse width, and waveform shape of the load xenon lamp current pulse in the pulse forming network. The resistance of the xenon lamp is a non-linear load according to equation (2). In order to make the discharge circuit of the xenon lamp release as much energy as possible and obtain a larger current pulse, the discharge of the xenon lamp should be in a critically damped state. The pulse width \( t_p \) is about \( \frac{3}{\sqrt{L C}} \) (\( L \) is the pulse smoothing inductance, \( C \) is the energy storage capacitor). Approximately 97% of the energy is released during this period. There is a formula (3) in the critically damped state \( 6 \).
\[
\alpha = K_0 (V_0 Z_0)^{\frac{1}{3}}, \quad t_p = \frac{3}{\sqrt{LC}}, \quad Z_0 = \frac{L}{\sqrt{C}}
\]
(3)

\( V_0 \) is the initial charging voltage of the capacitor, the initial energy of the capacitor \( E_0 = \frac{1}{2} CV_0^2 \) in the formula.; which put into the formula (3), the inductance \( L = \frac{t_p^2}{9C} \) can be obtained. If the parameter \( K_0 \) of the xenon lamp, the required input energy \( E_0 \) and the current pulse duration \( t_p \) are known, the energy storage capacitor \( C \) and the pulse smoothing inductance \( L \) can be obtained.

3.2. High-voltage pulse synchronous trigger circuit
The high-voltage pulse synchronous trigger circuit was an important module in the entire power supply system, which determined whether the xenon lamp trigger was reliable, and could ensure the synchronization of the trigger signal, and minimized the delay of the discharge circuits. It was mainly composed of main charging circuit, trigger circuit, driving circuit, high voltage pulse forming circuit.

The circuit schematic was shown in figure 2. The main charging circuit was composed of a rectifier bridge, a full-bridge inverter composed of high-frequency power MOS tubes, a high-frequency step-up transformer, a high-voltage silicon stack rectifier bridge, and an RC charging circuit. The function was to output AC35V after the 220V mains would be stepped down by the transformer. After full-bridge rectification, filtering, full-bridge inversion of high-frequency power MOS tubes, high-frequency transformer step-up, high-voltage silicon stack rectification, R255-R259, and the energy storage capacitor E202 would be finally charged. After passing through the SCR D206, the charging voltage would be applied to both ends of the Xenon lamp \( V_{\text{OUT}+} \), and \( V_{\text{OUT}-} \) electrodes, waiting for the trigger pulse signal.
According to the characteristics of pulsed xenon lamp discharge, the energy stored in the storage capacitor is released by the discharge of the xenon lamp, so the energy of a single pulse is calculated by calculating the energy of the storage capacitor.

$$W = \frac{1}{2}CU^2$$  \hspace{1cm} (4)

The performance of UV pulse disinfection robot required that the energy of a single pulse was more than 10J. If the charging capacitor was selected as 22µF/2kV, according to formula (3), the calculated energy storage capacitor voltage was more than 1kV. The flat-wave inductor was 22µH. The pulse frequency of STM32 was set to 5-12Hz.

The trigger circuit adopted high-power SCR as the trigger switch, which has the characteristics of small size, relatively simple structure, and strong functions. SCR is a semi-controllable device, which can only be controlled to be turned on, but not to be turned off. The PE12 pin of STM32 output electrical pulse signals to SCR D206, 70TPS12.

The driving circuit mainly adopted Q206, BCP56-16TIG triode, which function was to amplify the STM32 electric pulse signal. The entire trigger and drive circuit was isolated using transformer L205 as shown in Schematic 3, so that the voltage in the main discharge circuit wouldn’t be introduced into the control circuit.

The high-voltage pulse forming circuit was the main circuit of the pulse xenon lamp power system, which was mainly composed of energy storage device, the SCR switch device, pulse transformer, transmission cables and the load xenon lamp. Its function was to provide high-voltage trigger pulse signals for the pulse xenon lamp. The output voltage of high frequency transformer T201 was boosted by Voltage Doubling circuit to charge the capacitor C262. When the voltage reached 1000V, the discharge tube would be broken down. Once the gate of the SCR receives the threshold voltage signal
at this time, and the drain and source of the SCR would be turned on instantly. After the energy on the energy storage capacitor passed through the SCR D206, the smoothing inductor L206 and the pulse transformer T202, a high-voltage electric pulse signal with an amplitude more than 20kV would be generated, which was loaded on the xenon lamp, so that the xenon lamp instantly broken down and discharged. The discharge loop was formed between the capacitor and xenon lamp, the xenon lamp lit.

3.3. PWM phase shift control circuit

The schematic of the PWM phase-shifting control circuit was shown in figure 4. The UC3825 was used as the main control chip which is a dedicated PWM controller with the advantages of simple peripheral circuit structure and high frequency. This circuit realized the PWM output of MOS tubes drive signal, the overcurrent protection of the full-bridge inverter MOS tube, the protection of the DC charging voltage and the constant current control of the xenon lamp. The drive signal of the xenon lamp charging circuit was generated by the 11 and 14 pins of UC3825 which was amplified by U104 (A6387DTR) to drive the switching device MOSFET to work. The STM32 control signal was sent to the CT pin of UC3825, and the overcurrent protection and overvoltage protection were sent to the limit pin of UC3825 after the sampling circuit.

UC3825 would adjust the duty cycle of the MOS tube drive signal after detected the xenon lamp current, the DC charging voltage and the instantaneous current of the full-bridge inverter, which realized constant voltage control and overcurrent protection.

3.4. DC voltage sampling and voltage regulation control circuit

The schematic of DC voltage sampling and voltage regulation control circuit was shown in figure 5. The sampling voltage was outputted through a high-precision resistor divider: One path was input to the STM32 through an isolation circuit composed of the optocoupler TIL300A, and compared with the STM32 preset voltage. The output signal was used as the control voltage of the voltage regulator module, which control the output of the voltage regulating module, and thus control the charging voltage VDC of the energy storage capacitor; The other was inputted to the control chip UC3825 to form the over-voltage protection and voltage feedback loop, then the charging voltage VDC of the energy storage capacitor would be adjusted in real time. Thus the DC charging voltage would be stabilized at the set voltage.

4. The design of STM32 control software

This paper adopted STM32 to realize PWM wave output function, analog-to-digital conversion function and various protection functions of the system. The STM32 control software program was a
This crucial step to realize the hardware circuit of the pulsed xenon lamp power supply. This paper adopted RS-232 communication technology to realize the communication function. Human can set the pulse xenon lamp irradiation time, DC charging voltage, and charging frequency on the touch screen. Ultraviolet pulsed strong light disinfection robot was equipped with sensors inside. When the xenon lamp is turned on, if someone approaches, the system will automatically stop the irradiation. When no one is detected around, the xenon lamp continues to irradiate and disinfect, that completely protect the safety of the surrounding personnel. The overall flow chart of software was shown in figure 6.

5. Test results and analysis
A pulsed xenon lamp with a 196mm×Φ10mm and a resistivity of $12\Omega \cdot \text{A}^{1/2}$ developed by the Shanghai Optical Machinery Institute was used as the load in the sample test. A series of debugging and tests of the whole xenon lamp power supply was carried out. The waveforms were tested by a digital oscilloscope. The main test data were: DC charging voltage 1kV-3kV, output pulse current peak value 1kA-3kA, pulse width about 50μS. When the DC charging voltage of the pulsed xenon lamp was 1kV, the charging and discharging waveform diagram of the energy storage capacitor was shown in figure 7. It could be seen that the charging time of the energy storage capacitor was between 80mS-200mS using a probe with a voltage amplification of 500 times.

![Figure 5. Schematic of DC voltage sampling and voltage regulation control circuit.](image-url)
The waveform of the output current pulse signal measured with an oscilloscope was shown in figure 8. The main technical parameters were: the peak value of the output pulse current was 1kA, the duration of the current pulse was 50µS. The measured current pulse amplitude and pulse width were basically consistent with the calculated values.

This paper has completed the design of the driving power supply of the UV pulse disinfection robot, which could successfully light the load xenon lamp, operate stably, and perform disinfection work.

6. Conclusions
This paper designed and analyzed the electrical characteristics of the pulsed xenon lamp with 196mm×Φ10mm and resistivity 12Ω·A$^{1/2}$, high-voltage synchronous trigger circuit, PWM phase shift control circuit, and DC voltage sampling and voltage regulation control circuit. The device parameters were optimized through physical experiments. This paper developed a pulsed xenon lamp power supply with a high-voltage pulse synchronous trigger function, a DC charging voltage of 1kV-3kV, an output pulse current range of 1kA-3kA, and a pulse width of 50µS. The experimental test and theoretical calculation results were basically consistent. The power supply in this paper adopted simple and reliable control signal isolation circuit and the method that one end of the capacitor was grounded, etc., which effectively suppresses the rise of ground potential, improves the reliability and anti-interference ability of the xenon lamp power supply, and meets the technical requirements of the light source of the ultraviolet pulsed strong light disinfection robot. The power system runs stably, and the xenon lamp can emit UV pulse flash light for disinfection operation.
Figure 7. Charging and discharging waveform diagram of energy storage capacitor.

Figure 8. Discharge current waveform diagram of Xenon lamp.

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