Design and Research on the Control Circuit of Capacitive High Power Pulse Power Supply

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Abstract. Based on the function of the high-power pulsed power supply control circuit, this article reasonably selects the control device combined with the emission characteristics of the electrochemical gun, and proposes a control circuit design plan, and effectively improves the circuit through the trial of the control circuit.

1. Introduction
The high-power pulse power supply is a device that provides electromagnetic energy to the pulse power device load, which is mainly composed of multiple pulse capacitor banks as energy storage units in parallel. Compared with other pulsed power supplies, high-power pulsed power supplies have the advantages of low cost, flexible and adjustable waveform, low charging power, simple energy storage, etc., and convenient transportation, which promotes the wide application of high-power pulsed power supplies in the field of electrothermal chemical guns.

2. Function analysis of control circuit of high power pulse power supply
The high-power pulse power supply is a device that provides electromagnetic energy to the pulse power device load. It is mainly composed of multiple pulse capacitor banks as energy storage units in parallel. Compared with other pulsed power supplies, high-power pulsed power supplies have the advantages of low cost, flexible and adjustable waveform, low charging power, simple energy storage, etc., and convenient transportation, which promotes the wide application of high-power pulsed power supplies in the field of electrothermal chemical guns.

During the operation of the high-power pulsed power supply, the control circuit will monitor the status of each stage of the power supply system in real time. According to the monitoring structure, it will immediately issue corresponding control instructions to jump to the system status. Specifically, the main function of the control circuit is to control the charge and discharge of the high-power pulsed power supply [3]. Under normal circumstances, there are abnormal warning protection devices such as overcurrent, and overheating in the charging system of high-power pulse power supply. However, these devices only play a protective role for the charging system during operation. However, for example, the surge voltage protection effect generated when the high-power pulsed power supply is discharged and corresponding fault conditions may still be caused. Therefore, in the control circuit design, isolation and protection circuits should also be configured in the energy storage unit and the charging subsystem. The concrete circuit is shown as in figure 1.
In figure 1, Kp (charging isolation switch) and Kg (ground insulation isolation switch) will be turned on after the high-power pulsed power supply is charged to prevent the high-power pulsed power supply from generating surges due to load and other factors during power generation voltage to avoid malfunctions such as damage to the insulation of the charging equipment. Cp (capacity capacitor) is connected to the charging output terminal of the safety circuit (Kp and Rp resistances together to form a circuit) [4], which can effectively prevent the mischarging caused by the no-load problem during the operation of the high-power pulse power supply. In turn, failures such as damage to the charging society caused by the rise of the voltage at the end of the charging circuit are avoided.

After the pulse capacitor of the high-power pulse power supply stores energy, the control circuit will issue a power generation command to the pulse capacitor, and control the pulse capacitor to emit electrothermal chemical guns. Under normal circumstances, the launch accuracy and consistency of the electrothermal chemical gun will have a positive correlation with the energy storage of the pulse capacitor in the high-power pulse power supply. Therefore, in the design process, the control circuit must meet the effect of being able to accurately control the pulse capacitor charging voltage value [5]. In this regard, in the design, a voltage divider-voltage generator group can be connected in parallel in the charging container group to achieve this effect. The specific situation is shown in figure 2.

During the operation of the high-power pulsed power supply, the firing of the electrothermal chemical gun may be cancelled under the influence of safety factors or other factors. In this case, the electric energy stored in the pulse capacitor will not be effectively released. After the electrothermal chemical cannon is fired, a certain amount of electric energy will remain in the pulse capacitor and not
be released. At this time, it is necessary to measure and release the electric energy in the pulse capacitor by a charging voltage measurement and control and a safe discharge circuit. In figure 2, Kd is the safety release switch and Rd is the safety release resistance. During operation, the safety release switch will be effectively controlled by the control circuit.

In summary, the control circuit should have the following functions.

1. High voltage relay switch control. The control circuit must be able to control the operating state of the high-voltage relay switch corresponding to the different working stages of the high-power pulsed power supply.

2. Charging control. The control circuit should control the charging circuit to start and stop charging.

3. Discharge control. The control circuit can control the high-power pulse power supply to launch the electrothermal chemical gun after the pulse capacitor is charged.

4. Emergency stop control. During the working process of the system, if a certain part of the fault or abnormal situation occurs, the system can automatically control the emergency shutdown of the equipment and guide the energy storage in the pulse capacitor to be released safely.

3. Selection of control devices

As mentioned above, the launching process of the electrothermal chemical gun is usually accompanied by strong mechanical vibration and electromagnetic interference. Therefore, when selecting control devices, priority should be given to selecting control devices with good anti-electromagnetic interference and anti-mechanical vibration [6]. After analyzing and researching common control devices on the market, it is found that solid state relays can meet this requirement and act as a non-contact switching device composed of solid state electronic components. It has been widely used in recent years and has shown good application effects. Solid state relays mainly realize management and relay switching effects through the photoelectric characteristics of electronic components and semiconductor devices. Compared with conventional relays, solid-state relays do not have electromagnetic coils, so the ability to resist electromagnetic interference and mechanical vibration is relatively excellent, which can meet the design requirements. Solid-state relays will be used in the control circuit design process.

4. Control circuit design

Based on the existing research results, combined with experience and knowledge, the capacitive high-power pulse power control circuit design scheme is finally designed in figure 3. In the design, in order to ensure that the control circuit can collect the status information of the controlled relay switch in real time, it can ensure the accuracy and effectiveness of the control circuit control. This article will be equipped with position stroke auxiliary switches for the design of high-voltage electromechanical switches.
Figure 3. Design of control circuit for capacitive high power pulse power supply

In figure 3, KM1-4 are 4 solid state relay switches, while SB1-4 are 4 self-locking buttons. When the high-power pulse power supply is energized, under the control of the button SB1, KM1 and KM2 will be activated, and the Kd high-voltage relay switch will be energized. Afterwards, high-voltage relay switches such as Kc, Kg, and Kp will also act in succession. Keenlow will make preparations for the next charging of the high-power pulse power supply. After Kp is started, Kc1 and KC2 nodes will also be started one after another. This design can effectively improve the logic action of the control circuit and the effect of anti-misoperation.

However, after the control circuit detects that the system is operating normally, HL1 lights up, and then KM3 is activated by starting the SB2 self-locking button to prompt current to enter the pulse capacitor for charging. After the actual voltage of the pulse capacitor reaches the preset value, KV starts to move, and KV1 performs a disconnection action, causing KM2 to lose power. After that, high-voltage electromechanical switches such as Kc, Kg, and Kp will return one after another. Among them, the return of Kp will cause KM3 to start to lose power, which will cause Kc and Kg to be disconnected, the charger will stop working, and meet the prerequisite requirements of high-power pulse power discharge. HL1 are off, KV2 is on, and HL2 are on. It indicates that the high-power pulse power supply has been electrocuted. At this time, the KM4 solid-state relay switch is controlled by the self-locking button SB3 to start, prompting the high-power pulse power supply to launch the electrothermal chemical gun.

If abnormal operation or malfunction occurs during each of the above-mentioned operation stages, the control circuit will urgently control the shutdown of the high-power pulse power supply and safely release the electric energy in the pulse capacitor. In this regard, this effect can be achieved by controlling KM1 to lose power through the self-locking button SB4. But after KM1 loses power, Kd will be reset and closed, which in turn causes the energy stored in the pulse capacitor to be safely released through the Rd resistor. At the same time, Kd is disconnected, and high-voltage electromechanical switches such as Kc, Kg, and Kp are successively reset, prompting the system to stop completely, and the entire system will return to the initial state after the electrothermal chemical gun is launched.
5. Circuit trial and improvement

The capacitive high-power pulse power supply control circuit designed in this article is made into a real object, and placed in a specially customized steel box, and installed in a high capacitance with a capacitance of 8000μF, a pulse forming inductance of 10μH, and a working voltage of 15kV. On the power pulse power supply, the control circuit designed in this article is effectively tested by simulating the working conditions of the electrothermal chemical gun.

Through testing, it is found that the solid-state relay switch in the control circuit designed in this paper has a malfunction. After many tests, it is found that the probability of this malfunction can reach more than 7%, and it should be dealt with in time [7-8]. After analyzing and studying the malfunction of the solid-state relay switch, it is found that the reason is that the strong electromagnetic interference generated during the charging and discharging process of the high-power pulsed power supply will affect the normal operation of the solid-state relay switch and cause the malfunction. According to this problem, on the one hand, the original high-voltage electromechanical switch is changed to a high-power electromagnet switch. On the other hand, an auxiliary protection circuit such as surge absorption is added for the solid-state relay switch. The specific circuit design scheme is shown in figure 4.

![Figure 4. Auxiliary protection control circuit](image)

6. Conclusion

According to the requirements of capacitive high-power pulsed power supply control circuit function and the practical development direction of electrothermal chemical gun, a set of high-power pulsed power control circuit is designed by solid-state relay switch and simulation of electrothermal chemical gun operating conditions. The circuit is tested. It is found that the solid-state relay switch malfunctioned, and put forward corresponding solutions. After improvement, the capacitive high-power pulsed power supply control circuit designed in this article is compared with the existing control circuit, and it is determined that the control circuit designed has stronger electromagnetic interference and mechanical vibration compatibility. It not only has a wider range of applications, but also has a good application prospect and it is worthy of popularization and application.

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