Design of spike voltage generation system for tank gun ammunition setting test

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Abstract. In order to test the voltage spike interference of the tank gun ammunition setter, a spike voltage generation system is designed in this paper. The system adopts rectifier filter and series voltage stabilizing circuit, combined with single chip microcomputer control circuit, and converts 220V, 50HZ alternating current into spike voltage through post-stage RLC series circuit, and studies the influence of post-stage circuit inductance value on spike voltage rise time. Theoretical calculations and simulations verify that the system can generate spike voltages that comply with GJB298-87, which is of great significance to the test of voltage spike interference of tank artillery ammunition mounters and other military vehicle electronic equipment.

1. Introduction
Information-based warfare requires timely cross-linking of useful information between weapon systems in order to strike targets quickly, in real time, and accurately [1]. The setting technology of the fuze is one of the key technologies for the position control of the explosive point of the ammunition. The setting controller is the medium of the cascaded weapon fire control system and the fuze. According to the battlefield environment and combat objectives, each ammunition can be set flexibly through the setter, and the best fuze action mode and control information can be selected. Realize precision strikes, improve the combat power of ammunition, greatly increase the probability of weapon damage and realize weapon system automation [2]. In order to adapt to the fast-developing fuze technology, higher and more complex requirements have been put forward for the function of the setting controller. In the process of R&D and production of military products, product performance testing is indispensable.

Tank gun ammunition has the first hit requirement. Through the fire control computer, primer and ammunition fuze, information is cross-linked to complete the pre-launch information transmission of the ammunition in the chamber, and realize the fuze initiation method and the initial information loading of the ballistic correction ammunition [3]. The tank gun ammunition setter is assembled on the tank and is powered by the tank’s on-board power supply. The actual power supply environment of the tank’s on-board power system is complex, such as undervoltage changes during the period of voltage deviation from the steady-state voltage caused by starting the engine or switching inductive. The spike voltage caused by the complex high-frequency current wave under load. Therefore, in order to ensure the high reliability of the setter, it is necessary to design a spike voltage generating system to evaluate the anti-interference ability of the setter.

At present, many predecessors have done a lot of research on the spike voltage withstand test of aircraft electrical equipment [4-7], but there is no relevant design for the spike voltage generation
This article mainly aims at the tank gun setting platform, designs the spike voltage generation system, and simulates with ORCAD and MULTISIM software, analyzes the influence of the system circuit electrical parameters on the spike waveform, and finally verifies that the spike voltage generated by the system is consistent GJB298-87 requirements.

2. Performance requirements
GJB298-87 specifies the limit value and steady-state voltage range of the transient characteristics of the 28V DC power supply system for military vehicles. Its purpose is to adapt the vehicle power supply and the electrical equipment by limiting the power supply performance within a certain range and limiting the power requirements of the electrical equipment [8].

GJB298-87 stipulates that the equipment under test should work at the rated voltage, and the amplitude of the spike voltage should be 250V when the simulated spike voltage is applied to the equipment under test, and the rise time should not exceed 50ns; the oscillation frequency is greater than 100KHZ and less than 500KHZ; The energy of the spike voltage is not less than 15mJ.

3. Working principle
Figure 1 shows the principle block diagram of the spike voltage generating system.

According to the above scheme, the main circuit of the system is shown in Figure 2.

The spike voltage generation system designed in this paper uses a 220V, 50HZ single-phase AC power supply. The 220V AC voltage is rectified into a DC voltage of about 300V through the bridge rectifier circuit and the capacitor filter circuit. A voltage stabilizing circuit is added after the capacitor filter circuit, the zener diode is reversely cut off and the resistor divides the voltage to stabilize the DC voltage value at about 250V. The single-chip control circuit obtains the rectangular pulse voltage by controlling the on and off of the circuit. The rectangular pulse voltage finally generates a spike voltage through the RLC series circuit.

4. Single-chip control circuit design
The gate voltage VControl of NMOS transistor Q2 is controlled by the single-chip microcomputer, as shown in Figure 3 for the single-chip control circuit diagram.
Si8261AAC-C-IS is an isolated gate driver, used to isolate the 3.3V operating voltage of the microcontroller from the 12V control terminal voltage. The single-chip microcomputer inputs a 0-3.3V PWM wave from the Vin port. When Vin inputs a high level, the transistor Q3 is turned on, the isolated gate driver cathode C is grounded to a low level, and V0 outputs a high level and Q2 is turned on; when Vin input is high At the level, the transistor Q3 is cut off, the cathode C of the isolation gate driver is suspended and set high, and the V0 output low level Q2 is cut off. By controlling the on-off time of the high and low levels of the Vin terminal, the on-off of Q2 can be controlled to obtain a rectangular pulse square wave with a certain frequency.

5. The generation and design calculation of spike waveform
The spike voltage is generated by a rectangular square wave through an RLC series circuit. The sum of the spike voltage rise time and the spike voltage decay time output from the resistor R3 is equal to the charging time of the capacitor C3. The output circuit of the main circuit can be equivalent to Figure 4.

![Figure 4. Equivalent diagram of the output circuit of the main circuit](image)

According to Figure 4, when the capacitor C is charged, the voltage \( U_c = U_i \) at both ends of the capacitor, the resistance R and the inductance L are regarded as the equivalent resistance in series with the capacitor C to form a first-order RC differential circuit. Inductance of inductance \( L = 2\pi fL \), where \( f \) is the frequency of the rectangular pulse voltage \( U_i \). The equivalent resistance of the charging circuit is:

\[
R_e = R + XL = R + 2\pi fL
\]  
(1)

According to the RC charging circuit formula:

\[
U_c = U_i \exp\left(-t / RC\right)
\]  
(2)

The formula for the voltage across the charging capacitor C over time is:

\[
U_c = U_i \exp\left(-t / \tau\right)
\]  
(3)

Where \( \tau \) is the time constant of the charging circuit:

\[
\tau = (R + 2\pi fL)C
\]  
(4)

When \( t = 5\tau \), \( U_c = 0.99U_i \), the capacitor is considered to be charged at this time. The capacitor C and the resistor R are connected in series to form a first-order RC differential circuit. In order to make the single spike voltage rise to decay time within 1ms, the pulse width of the rectangular pulse voltage \( U_i \) is \( t_w \leq 1\text{ms} \). The normal operation of the differential circuit should meet the following requirements: the time constant \( \tau \) of the circuit should be much smaller than the pulse width \( t_w \) of the input rectangular pulse, that is, \( \tau \ll t_w \). It is generally considered that \( 5\tau \leq t_w \) can be considered to meet this condition, thus:

\[
(R + 2\pi fL)C \leq \frac{1}{5}\text{ms}
\]  
(5)

The spike energy is stored and released through the capacitor C. When the capacitor is fully charged, the amount of charge stored in the capacitor \( q = CU \), the energy \( W = qV \), then
\[ dW = d\left( qt \right) = d\left( CU_i t \right) = CU_i dt \]  
\[ \frac{dW}{dt} = CU_i \]  
\( U_i \) is the function of \( t \), namely \( U_i(t) \), to find the original function on both sides, we get:

\[ W = \frac{1}{2} CU_i^2 \]  

According to GJB298-87 requirements, the oscillation frequency is greater than 100KHZ, less than 500KHZ, and the peak pulse voltage energy is not less than 15mJ.

\[
\begin{cases}
\frac{1}{2} CU_i^2 \geq 15 \text{mJ} \\
100 \text{KHZ} \leq f_i \leq 500 \text{KHZ}
\end{cases}
\]  

Where \( f_r \) is the resonance frequency of the LC series circuit, \( f_r = \frac{1}{2\pi\sqrt{LC}} \).

From equation (8), we can get \( C \geq 480nF \), \( \frac{1}{\pi^2 C} \times 10^{-12} H \leq L \leq \frac{25}{\pi^2 C} \times 10^{-12} H \), take the capacitance \( C = 500nF \), then \( 2.03 \times 10^{-7} H \leq L \leq 5.07 \times 10^{-6} H \). Take the pulse width \( t_w = \ln 5 \) of the rectangular pulse voltage \( U_i \) and the pulse frequency \( f = 500 \text{HZ} \), then \( R_e \approx R \). From the formula (5), take the resistance \( R = 400 \Omega \).

When the inductor L coil passes current, a magnetic field is induced in the coil, and the induced magnetic field generates an induced current to resist the current passing through the coil. The inductance \( L \) has different inductance values and the spike voltage rise time \( t_s \) is different. Use ORCAD to simulate the output circuit of the main circuit of the spike voltage generating system, where the capacitance \( C = 500nF \) and the resistance \( R = 400 \Omega \).

Figure 5 shows the rising curve of spike voltage corresponding to different inductance values of inductance \( L \), from left to right corresponding to inductance values 50uH, 100uH, 200uH, 300uH, 500uH.

![Figure 5. Peak voltage rise curves corresponding to different inductances](image-url)
Figure 6. Fitting curves of spike pulse voltage rise time under different inductance values

It can be seen from Figure 5 that the greater the inductance $L$, the greater the rise time of the spike voltage $t_s$. Use MULTISIM software to simulate the circuit, as shown in Table 1, it is the spike voltage rise time under different inductance values.

| Inductance value ($\mu H$) | Spike voltage rise time $t_s$ (ns) |
|----------------------------|-----------------------------------|
| 0                          | 0                                 |
| 5                          | 85.02                             |
| 10                         | 198.31                            |
| 15                         | 281.91                            |
| 20                         | 316.65                            |

Polynomial fitting is performed on the data in Table 1 through MATLAB. The fitting result is shown in Figure 6. The spike voltage rise time is positively correlated with the inductance value. When the spike voltage rise time is $50\,ns$, the corresponding inductance value is $2.394\,\mu H$. In order to make the spike voltage rise time $t_s \leq 50\,ns$ and the oscillation frequency is greater than 100KHZ and less than 500KHZ, the inductance value should satisfy $2.16 \times 10^{-7} \,H \leq L \leq 2.39 \times 10^{-6} \,H$.

6. Circuit simulation waveform analysis
Take the resistance $R = 400\Omega$, the inductance $L = 2.2\,\mu H$, and the capacitance $C = 500\,nF$ to the output circuit of the main circuit of the spike voltage generating system, and input the mains 220V and 50HZ AC. The output spike voltage is shown in Figure 7 through MULTISIM simulation.
It can be seen from Figure 7 that the amplitude of the spike voltage output by the system is $250V$, the spike voltage rise time $t_r = 38.29\text{ns}$, the calculated oscillation frequency $f_r = 151.7\text{KHZ}$ and the spike energy $W = 15.6\text{mJ}$ meet the GJB298-87 requirements.

7. Conclusion
This paper designs a spike voltage generation system, and studies the influence of the inductance value in the output circuit of the system on the rise time of spike voltage. By controlling the electrical parameters of the circuit, the spike waveform that meets the requirements of GJB298-87 is obtained. The simulation test of drug loaders and other military on-board electronic equipment is of great significance.

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