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Research on electromagnetic orbital accelerator

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Abstract: *This paper describes the design process of the electromagnetic track accelerator system from both hardware and software aspects. It adopts three-level track acceleration and three groups of capacitors to store energy, and adds ZVS boost module to realize continuous acceleration of the electromagnetic track. The system works reliably.*

Keywords: *Electromagnetic orbital; Accelerator; Three stage electromagnetic gun; MCU*

1. Introduction

With the continuous upgrading of traditional charging weapons, its development seems no longer able to meet the country's demand for kinetic energy weapons. In the 21st century, many countries began to study electromagnetic weapons. Compared with traditional artillery weapons, electromagnetic weapons can store more energy, so they can shoot bullets to the target at an extremely fast speed, without recoil, and have a high hit rate[1].

In this paper, STC89C52 is used as the main control to realize the rotation of multiple capacitor banks, improve the firing frequency of the projectile while maintaining the exit speed of the projectile, and solve the tedious charging and discharging process of the manual electromagnetic gun.

2. System design block diagram

The system is composed of power module, microcontroller, relay, silicon controlled rectifier, voltage booster module (ZVS) and three-stage accelerator, as shown in Figure 1.

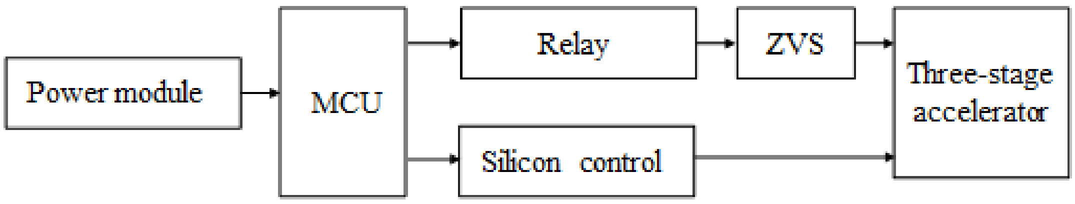

Figure 1: System Design Block Diagram.

3. The hardware design

3.1. Power circuit

In order to drive the high-power ZVS boost module and ensure the system has a certain degree of mobility, the system uses 4S high polymer lithium batteries. Since the voltage of the 4S lithium battery is between 14.8V and 16.8V, it needs to be depressurized to supply power to the microcontroller, and the collector of the triode will also be directly powered by the lithium battery, so the power supply part needs to provide three voltages, as shown in Figure 2.

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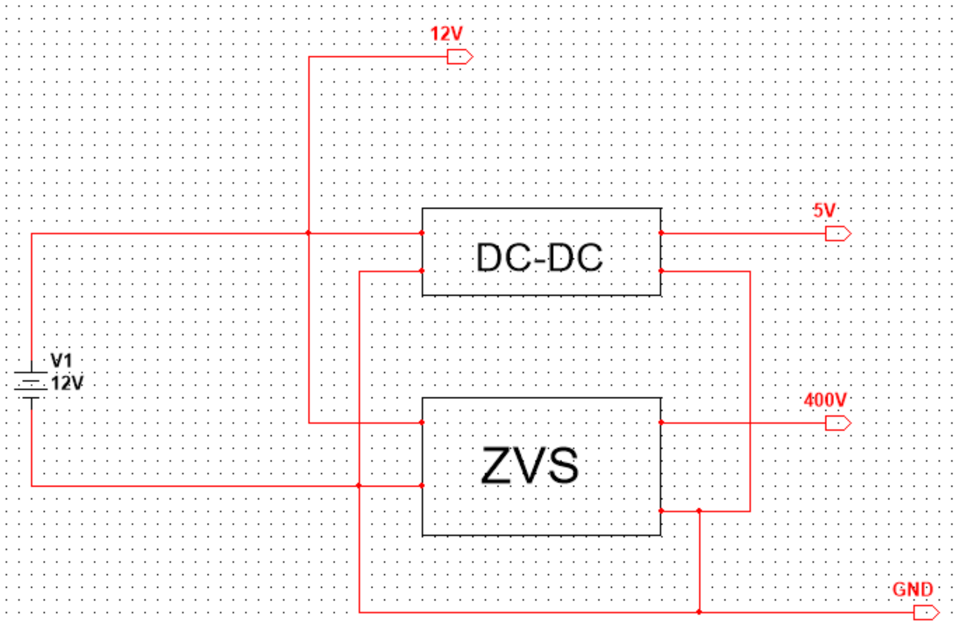

Figure 2: Power circuit diagram

3.2. Signal amplification circuit

Since the normal current between the pins of STC89C52 single-chip microcomputer is only 5mA, in order to enable it to control the conduction of silicon controlled rectifier normally, the signal of the pins must be amplified to reach the trigger current of 50mA~200mA that can drive 70TPS12 silicon controlled rectifier. The amplifier circuit mainly uses SS8050 triode for current amplification, as shown in Figure 3.

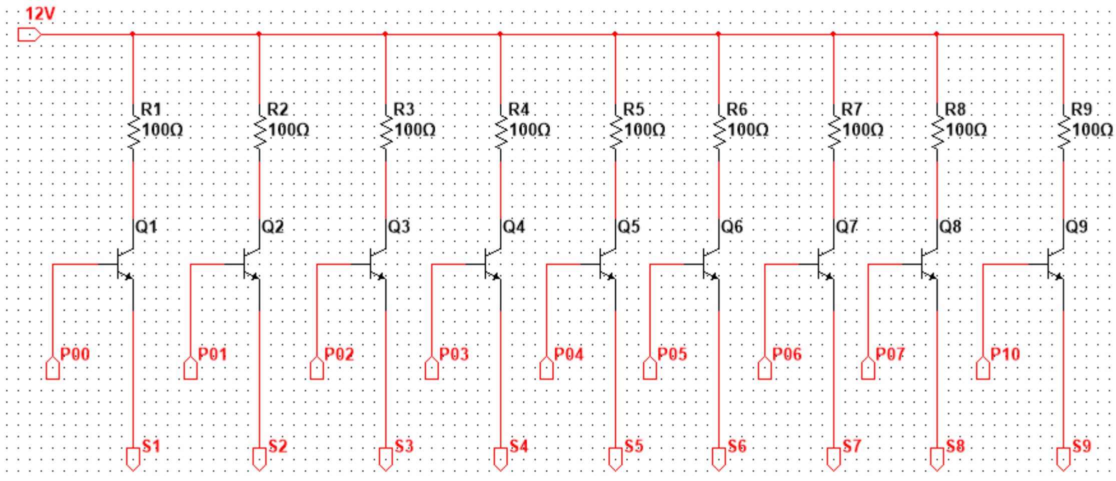

Figure 3: Schematic Diagram of Signal Amplification Circuit

3.3. Charge and discharge control circuit of capacitor bank

The capacitance used by the system is 500V. To ensure the normal operation of the circuit, high-power silicon controlled rectifier must be used to control the charging and discharging of the capacitance. The system selects 70TPS12 thyristor as the capacitor bank charging and discharging control circuit. The repetitive peak reverse voltage of 70TPS12 is 1200 V, the maximum holding current is 200 mA, and the maximum gate trigger current is 100 mA; The rated average on state current is 70 A, and the maximum temperature resistance is 125 degrees[2], meeting the system requirements, as shown in Figure 4.

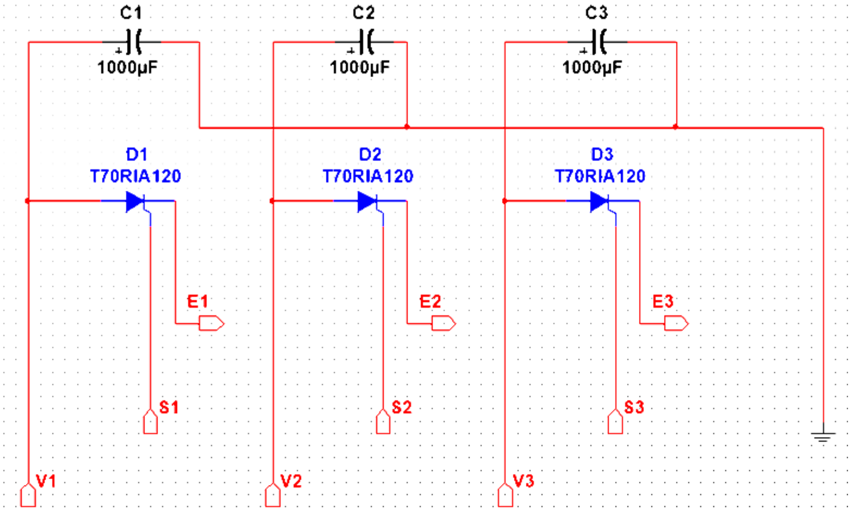

Figure 4: Capacitor charging and discharging control circuit

3.4. ZVS boost circuit

The circuit is mainly composed of two parts, ZVS part and LM555 control part. J1 and J2 are boost switch and transmitter switch respectively. LED1 and LED2 are charging indicator lamps. When lamp 1 is on, it means charging is in progress, when lamp 2 is on, it means charging is completed, and LED 3 is the startup signal lamp of the booster circuit. RP1 and RP2 are used to set the lower limit and upper limit of capacitor voltage respectively.

For a single-stage electromagnetic gun, after J1 is closed, 6V of LM7806 provides a stable working environment for LM555. At this time, because the second pin returns a voltage close to 0, LM555outputs a high level, lamp 1 is lit, and Q1 and Q2 are connected to make ZVS work to increase voltage. When the feedback voltage of the sixth pin reaches 4V, that is, two thirds of the input voltage, LM555 outputs low level, lamp 1 goes out and lamp 2 is on, and disconnection of Q1 and Q2 stops the voltage rise of ZVS. Due to the influence of R15, R13, RP1 and RP2 as well as capacitor self discharge, the voltage will slowly drop. With the decrease of capacitor voltage, the voltage of pin 2 also decreases. When the voltage of pin 2 drops to 2V, LM555 outputs high level, LED1 turns on, and Q1 and Q2 turn on to make ZVS work and start boosting until the feedback voltage of pin 6 reaches two-thirds of the input voltage again. Later, in order to keep the voltage within a certain range, this process will be repeated automatically before the launch. When launching, J2 is pressed down, Q1 turns on and pulls the voltage of pin 4 of LM555 to zero, ZVS is forced off, and SCR is triggered through R5, and the bullet is launched.The specific circuit is shown in Figure 5.

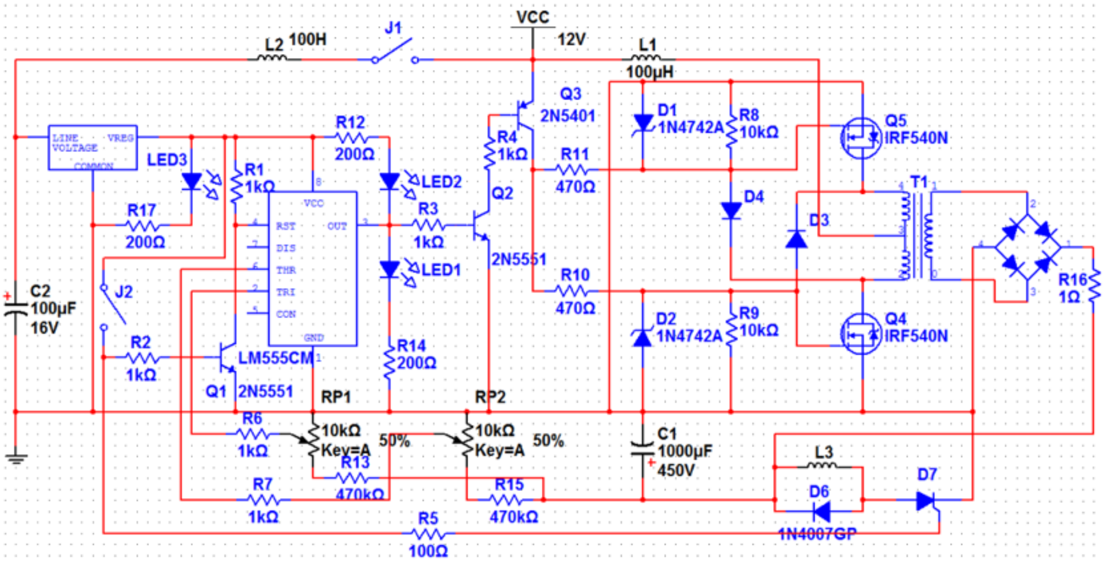

Figure 5: ZVS Booster Circuit

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3.5. Three stage electromagnetic track acceleration circuit

Three co directional coils are used for combination of three-stage track acceleration. The current inlet is divided into three ports, which can be independently powered by three groups of capacitors. The coils are serially sleeved on a PVC tube to form a three-stage electromagnetic track accelerator, as shown in Figure 6.

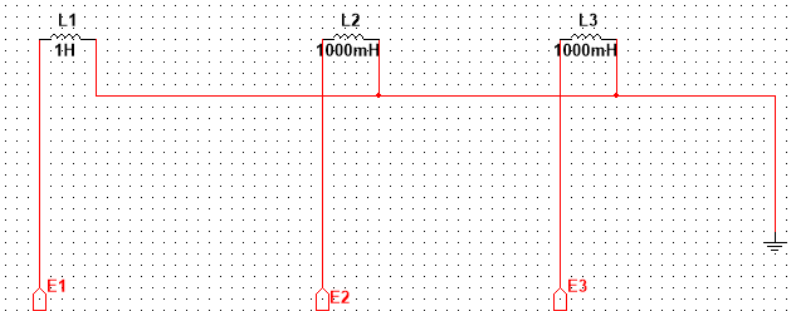

Figure 6: Circuit diagram of three-level electromagnetic track acceleration

4. The software design

4.1. Overall Program Design Flow Chart

After the system is powered on, immediately control the relay to close for 1s to charge the capacitor for 1s. After the relay is disconnected, delay a period of time to control the capacitor to supply power to the first stage coil. Set a time delay to ensure that the bullet will not pull back when the second stage coil supplies power. The same idea is to set the third stage coil to supply power. After completing a complete transmission, the second group of capacitors will be delayed for a period of time to repeat the transmission procedure again to complete the second transmission, and the third transmission will be conducted after the same completion. After running a set of consecutive programs, it returns to the starting position to close the relay again. In this way, the firing effect similar to that of an automatic rifle can be achieved. The overall program design flow chart is shown in Figure 7.

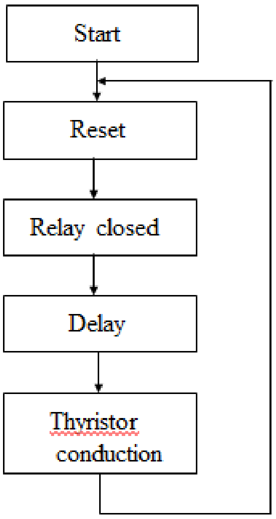

Figure 7: Program Design Flow Chart

4.2. Setting of delay (timing) parameters

In the firing process of a single-stage coil gun, the current distribution along the acceleration direction x of the acceleration coil is uneven. Therefore, in order to facilitate parameter calculation, the pipe is divided into m pieces evenly along the emission direction, each piece is a uniform ring, and its circumferential current is set to be evenly distributed along the section[3]. Therefore, the equivalent circuit of the system when the single-stage coil gun works is shown in Figure 8.

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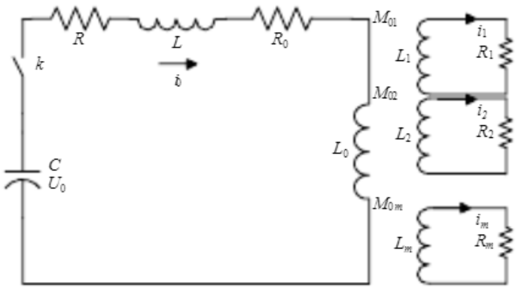

Figure 8: Equivalent Circuit Diagram

The letters in the equivalent diagram are explained as follows: R is the inherent resistance of the circuit, that is, the total resistance of all parts of the whole circuit, C is the capacity of capacitance, and L is the inherent inductance of the circuit. R0 and L0 are the resistance and inductance of the acceleration coil respectively. M01, to M0m are mutual inductance between acceleration coil and coil slice, R1 to Rm and L1 to Lm are resistance and inductance of pipe slice respectively. The charging voltage of the capacitor is U_0.

By adding time t, the following equation can be established for the above equivalent circuit:

$$
\begin{aligned}
&(L+L_0)\frac{\mathrm{d}i_0(t)}{\mathrm{d}t}+(R+R_0)i_0(t)=U_\mathrm{B}+\sum_{i=1}^{m}\frac{\mathrm{d}}{\mathrm{d}t}(M_{0i}i_i(t))\\
&\sum_{i=1}^{m}\frac{\mathrm{d}}{\mathrm{d}t}(M_{1i}i_i(t))+R_1i_1(t)-\frac{\mathrm{d}}{\mathrm{d}t}(M_{10}i_0(t))=0\ ,\\
&\sum_{i=1}^{m}\frac{\mathrm{d}}{\mathrm{d}t}(M_{2i}i_i(t))+R_2i_2(t)-\frac{\mathrm{d}}{\mathrm{d}t}(M_{20}i_0(t))=0\ ,\\
&\vdots\\
&\sum_{i=1}^{m}\frac{\mathrm{d}}{\mathrm{d}t}(M_{mi}i_i(t))+R_mi_m(t)-\frac{\mathrm{d}}{\mathrm{d}t}(M_{m0}i_0(t))=0\ ,
\end{aligned}
\tag{1}
$$

Where, mutual inductance:

$$M_{ii}=L_i, i=1,2,\cdots,m\ ;$$

Capacitive voltage:

$$U_B=U_0-\frac{1}{C}\int_0^t i_0(t)\mathrm{d}t$$

The inductance method is used to calculate the acceleration force on the missile body. The total stored energy in the system under ideal conditions:

$$W_m=\frac{1}{2}\sum_{i=1}^{m}L_iI_i^2+\frac{1}{2}L_0I_0^2+\sum_{i=1}^{m}M_{0i}I_iI_0 \tag{2}$$

If the bullet body moves in the x direction, then when the bullet body moves in the x direction (excluding the influence of gravity), the magnetic energy of the self inductance term does not change, but the magnetic energy of the mutual inductance term changes with x. The force acting on the projectile along the x direction at time t is (excluding other energy losses):

$$F(t)=\frac{\mathrm{d}W_m}{\mathrm{d}x}=\sum_{i=1}^{m}\frac{\mathrm{d}M_{0i}(t)}{\mathrm{d}x}I_i(t)I_0(t) \tag{3}$$

It can be seen from the above formula that in order to obtain the acceleration force of the projectile in direction x, it is also necessary to calculate the mutual inductance gradient of the acceleration coil

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and each piece of the coil along direction x. In a single-stage coil gun, the acceleration coil and the pipe can be equivalent to an ideal axisymmetric hollow cylinder. The mutual inductance and mutual inductance gradient between two hollow cylindrical coils can be calculated using the equivalent ring coil method[4].

According to Newton's second law, the force acting on the projectile at time t,

$$F(t) = m_p a(t)$$

According to this formula:

$$a(t) = \frac{F(t)}{m_p} = \frac{1}{m_p}\sum_{i=1}^{m}\frac{\mathrm{d}M_{0i}(t)}{\mathrm{d}x} I_i(t) I_0(t) \ ,$$

$$v(t) = v_0 + \int_0^t a(t)\mathrm{d}t = v_0 + \int_0^t \frac{1}{m_p}\sum_{i=1}^{m}\frac{\mathrm{d}M_{0i}(t)}{\mathrm{d}x} I_i(t) I_0(t)\mathrm{d}t,$$

$$x(t) = x_0 + \int_0^t v(t)\mathrm{d}t \circ \tag{4}$$

In the above formula: m_p is the mass of the projectile; A (t), v (t), x (t) are the acceleration, velocity and displacement of the projectile at time t.

According to the above calculation method, it is roughly calculated that the time for the missile body to reach the acceleration point of the second stage acceleration coil after leaving the first stage acceleration coil is about 21.4 ms. In the same way, it is calculated that the time to reach the acceleration point of the third stage coil is about 15.7 milliseconds. The flow chart of the delay program is thus designed, as shown in Figure 9.

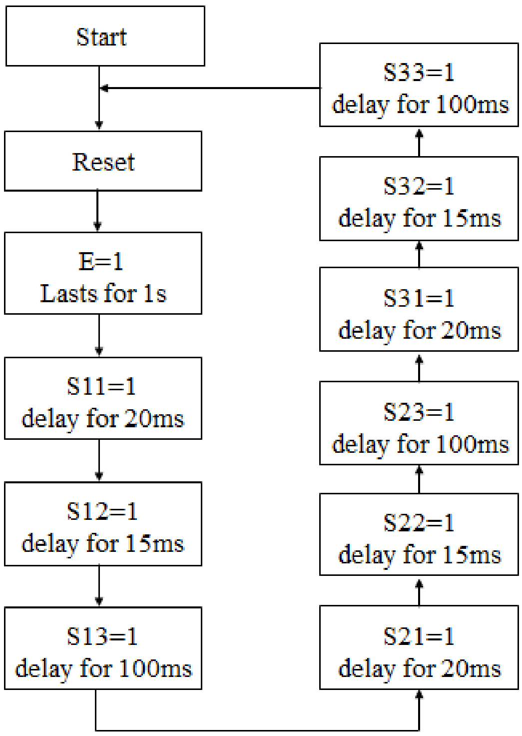

Figure 9: Delay Program Flow Chart

5. Conclusion

In this paper, three-level rail acceleration and three groups of capacitor banks are used to store

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energy to complete the regular discharge of three groups of capacitor banks. During the test process, the system is continuously optimized to achieve continuous acceleration of the electromagnetic track. The physical system is shown in Figure 10.

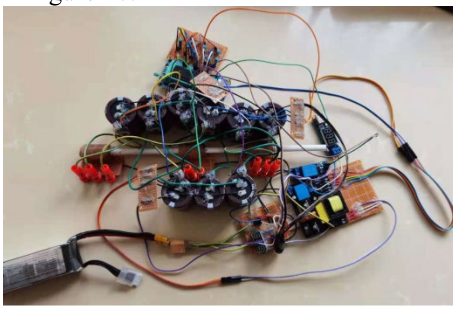

Figure 10: Physical Diagram of the System

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