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Design of Simulated Electromagnetic Curved Gun Based on STM32

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Abstract: *This paper designs a new analog electromagnetic curve gun system with an ARM microcontroller as the control core.the connection between variables such as the value of the voltage applied to the coil, the length of the coil, the trigger point, and the distance between the coils is studied and demonstrated in detail in this paper, so that the maximum initial velocity obtained by the bullet, according to the electromagnetic conversion experiment, a launch coil with high electromagnetic conversion efficiency is designed; a more scientific electron launch system, combined with infrared tubes to detect the position of the bullet in real time, realizes the full acceleration of the bullet by the acceleration coil, and greatly improve the firing speed under the condition of certain energy; When shooting a fixed target, the average error is 1.04cm. Using a solid iron column bullet with a diameter of 1cm and a length of 3cm, it can shoot up to 35m at a voltage of 2200uF and 490V, which is very practical. The experimental results show that the system is stable and reliable. Coil electromagnetic guns are smaller in size, simple in operation, low in cost, long in range, and high in accuracy.*

Keywords: *Coil electromagnetic gun, stm32f103, electromagnetic induction, SCR, servo gimbal*

1. INTRODUCTION

The electromagnetic gun is a weapon that converts electrical energy into magnetic energy and then into kinetic energy of shells based on electromagnetic theory. First of all, the electromagnetic gun uses magnetic energy to launch ferromagnetic shells. The speed of electromagnetic force far exceeds the speed of gunpowder expansion, which is also an important reason why its speed can reach a high level; Secondly, theoretically, the launching speed of the electromagnetic gun can be easily controlled by controlling the current intensity, which not only greatly improves the launching safety, but also can accurately control the initial velocity of the bullet; Then, the shells fired by electromagnetic cannons can easily destroy the target without the power of gunpowder explosion and only rely on the kinetic energy obtained by themselves. Moreover, the launching cost of the shells is low, and the various devices needed are convenient for production, storage, and transportation; Finally, it is highly concealed. There is no smoke, fire, and shock wave generated by a gunpowder explosion, and the recoil force and shock wave are also very small[1][2].

1.1 Related work

Most of the research focuses on shooting accuracy and power and rarely considers the automation and miniaturization of electromagnetic launchers[3]. Literature[17] combined the OpenMV camera with the laser ranging module to design a high-precision electromagnetic gun. Literature[5] designed a small portable electromagnetic gun using the principle of electromagnetic induction. Literature[6] conducts experiments, modeling, and simulation in harsh environments during the launch process. Literature[7] uses parallel processing to run the FPGA project to complete. However, according to the research results of electromagnetic guns at home and abroad, there are still inconvenient power supplies, heavy launching devices, and electromagnetic guns. There are a large number of technical problems that need to be overcome urgently, such as severe pipe damage[8][9].

The miniaturization of the electromagnetic gun can broaden the scope of use of the electromagnetic gun, especially for the flexible movement of combat vehicles, tanks and individual combat, which can greatly improve the combat ability. Therefore, the miniaturization of the electromagnetic gun will be of great value in the future.

2. Our Scheme

In this paper, the STM32F103 single-chip microcomputer is used as the microcontroller to design a feasible scheme for the launch system of a small analog curved electromagnetic gun. The system is mainly composed of an STM32F103 micro-controller minimum system, large capacitance charging and energy storage circuit, DC high voltage acquisition circuit, electromagnetic gun discharge circuit, steering gear pan-tilt, drive circuit, TFT touch LCD screen, virtual keyboard, and other parts.

2.1 Overall structure design

This system is mainly composed of STM32F103 minimum system, a large capacitor charging energy storage circuit, DC high voltage detection circuit, electromagnetic gun trigger discharge circuit, a steering gear head, and drive circuit, a TFT LCD screen, a virtual keyboard, other parts[10][11][12]. The overall block diagram is shown in Fig. 1.

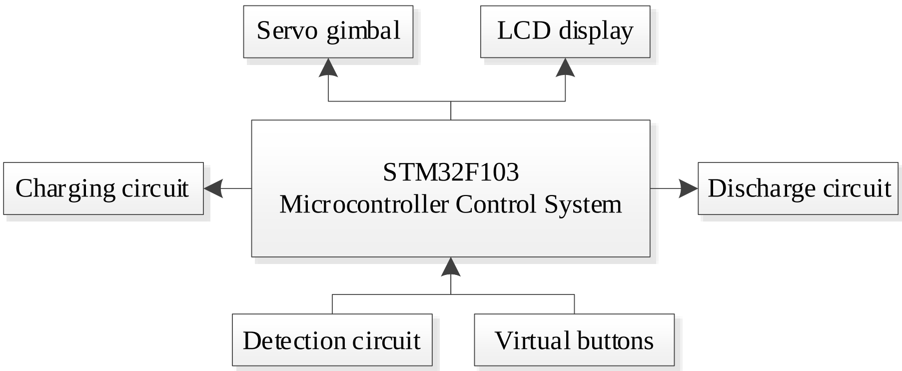

Figure1. *System Architecture Framework*

2.2 System function overview

High power pulse power supply can provide electric energy for the launcher, but how to miniaturize it is the main technical bottleneck at present. The energy storage capacitor can instantly discharge to replace the high-power pulse power supply in the electromagnetic gun launching system. The efficiency of the general low-power power supply can reach 80%~85%, so this design plans to use UC3843 chip as the boost control chip. Its main advantages are: it can drive the field effect tube conveniently; The number of pins is small, and the peripheral circuit needs fewer devices. The electromagnetic gun firing circuit is mainly composed of a microcontroller to control the silicon-controlled capacitor to coil discharge circuit. The electromagnetic gun firing needs to release the stored energy in a very short time, a key component is the high-power switch, in response to the launch switch problem, the discharge circuit is mainly composed of instantaneous current that can tolerate 1200A 70TPS12 SCR and relay components.

The coil electromagnetic gun uses the electromagnetic principle to convert electrical energy into magnetic energy and endows the projectile with magnetic force to attract the projectile[13]. The virtual keyboard manually inputs the target center and distance D and the deviation Angle α from the center axis. The data are processed by STM32F103 microcontroller. Then the controller generates a PWM signal to make the steering gear head move with the electromagnetic gun barrel in horizontal and vertical directions. After the charging voltage of the capacitor reaches the calculated voltage, the head of the steering gear is controlled to reach the specified position, and the capacitor is controlled to instantly discharge the coil so that the coil flows through a large current and generates a strong magnetic field to shoot the projectile out[14]. At the same time, the information on the target center position, barrel elevation, and capacitance-voltage are printed on the LCD screen.

3. Hardware Circuit Design

3.1 Design of Capacitor Charge and Discharge Control Circuit

The voltage of the capacitor is calculated from the coordinate data of the input target through the MATLAB software fitting formula, and then the microcontroller controls the DC-DC high-voltage boost module to charge the capacitor. The capacitor charging voltage can be calculated from Eq. (1).

$$V_C = V \times (1 - e^{-\frac{t}{RC}}) \tag{1}$$

In Eq. (1), τ=RC is also called the time constant, R is the charging current limiting resistance, C is the capacity of the capacitor, V is the power supply voltage, and t is the charging time. According to the real-time voltage of the capacitor fed back by the ADC acquisition and calculation, it is determined whether to continue charging and then the control of the capacitor voltage is realized. The operating frequency of the boost circuit can be determined by Eq. (2).

$$f = \frac{1}{2\pi\sqrt{R_6 R_7}} \tag{2}$$

Capacitor discharge can be done in two ways: mechanical switch and electronic switch. Although the mechanical switch can withstand a large current, its turn-on speed and turn-off speed are far less than that of the electronic switch. For the switch tube, after searching for references, it was found that the repetitive peak reverse voltage of the 70TPS12 SCR is 1200V. the maximum holding current is 200mA, the rated average on-state current is 70A, the surge current rating is 1400A, and the maximum gate trigger voltage is 1.5 V, the maximum gate trigger current is 100mA, and the maximum gate peak reverse voltage is 10V. The design principle of capacitor charging and discharging is shown in Fig. 2.

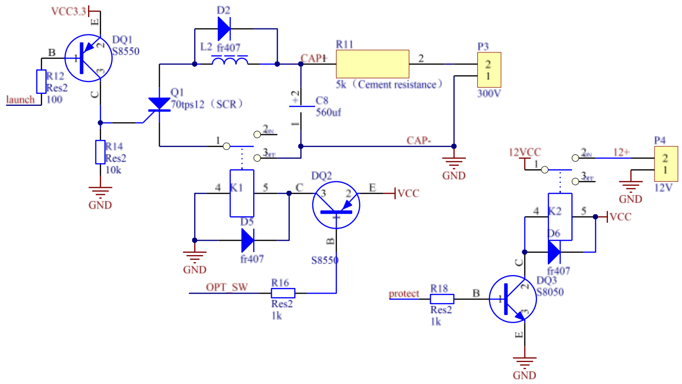

Figure2. *Capacitor charge and discharge control circuit*

3.2 Gimbal drive circuit design

The two-degree-of-freedom steering gear head composed of MG996R steering gear can easily drive the gun barrel to move in the left and right and up and down directions, and it is convenient to install the electromagnetic gun barrel. Then, by writing a program, the steering gear can move left and right first and then up and down to make the gun barrel accurately positioned[15]. The drive circuit is shown in Fig. 3.

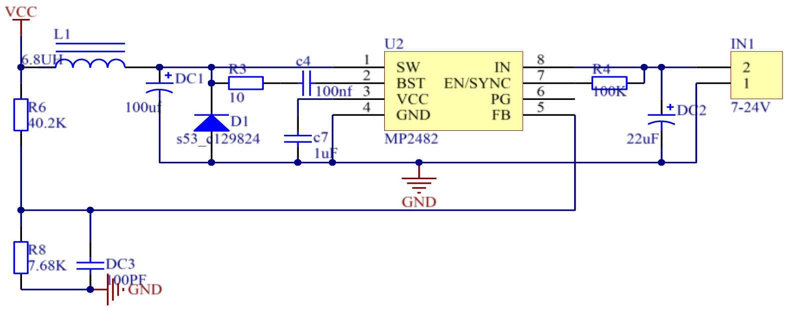

Figure3. *Gimbal drive circuit*

3.3 Voltage detection circuit design

This design needs to know the voltage of the capacitor in real-time, so according to the relevant theorem of the series circuit, a resistor divider circuit is designed by using R22 and R24 to measure the DC high voltage. The designed measurement range of the DC voltage is 400V, and the collected voltage analog quantity is 0-3V, and the analog voltage generated by the resistor divider passes through the voltage follower designed by the LM358 operational amplifier, so that the high-voltage input end is isolated from the output of the receiving end of the microcontroller, and then sent to the microcontroller for ADC analog-to-digital conversion processing. The real-time charging voltage can be calculated from Eq. (3).

$$U = u_I \times \frac{u_o}{255} \times \frac{R_{22}+R_{24}}{R_{24}} \tag{3}$$

U in Eq. (3) is the voltage across the capacitor, u_I is the sampled voltage output by the voltage divider circuit, u_0 is the maximum value of the sampled voltage, and R_{22} and R_{24} are the voltage divider resistors. The circuit design principle is shown in Fig.4.

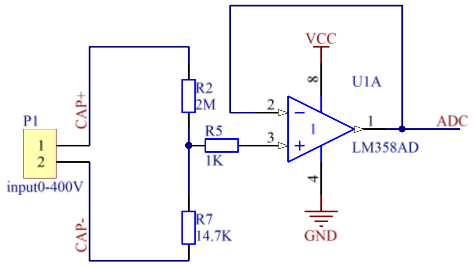

Figure4. *Voltage detection circuit*

3.4 Photoelectric sensor circuit design

When the projectile passes through the midpoint of the coil, the magnetic force generated by the coil will attract the projectile to slow down and form a reverse pull. As a result, the striking distance of the projectile will drop sharply. The coil was powered off, and after analysis, it was decided to use the infrared tube to detect the position of the shell[16]. The circuit design principle is shown in Fig.5.

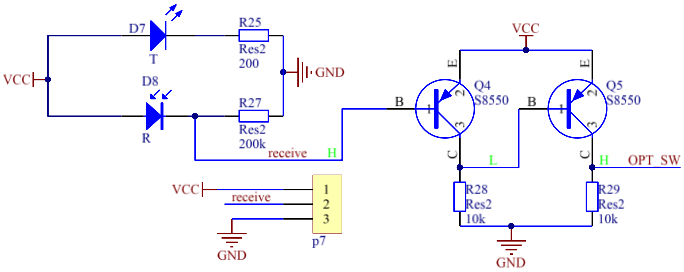

Figure5. *Photoelectric Sensor Circuit*

3.5 Selection and production of gun barrels and coils

The material of the gun barrel cannot use ferromagnetic materials, because the magnetic field generated by the coil can magnetize the ferromagnetic gun barrel, and it cannot be demagnetized immediately, resulting in the shell being attracted by the gun barrel and forming a large friction force on the wall of the tube. The strength of acrylic is relatively large, and it is necessary to withstand high temperatures for the barrel of the continuous firing of shells[17]. so the gun barrel is made of 11mm PVC pipe. The coil resistance has a great influence on the discharge time of the capacitor, and the relationship between the discharge time of the capacitor and the resistance and capacitance can be expressed by Eq. (4).

$$\tau = RC \tag{4}$$

From formula(4), it can be found that the smaller the time constant τ, the faster the discharge speed of the capacitor, and the easier and faster the coil converts the electric energy into the energy of the magnetic field. The coil resistance of the electromagnetic gun is the resistance R in the time constant. If the discharge speed of the capacitor is to be accelerated, it is necessary to find a way to reduce the resistance value of the coil[17]. The wire resistance can be calculated using Eq. (5).

$$R = \frac{\rho l}{S} \tag{5}$$

From Eq. (5), it can be easily seen that the resistance value R of the coil resistance is proportional to the length l of the coil wire, and is inversely proportional to the cross-sectional area S of the wire[19], so choose It is 0.8mm thick copper enameled wire, wound for 320 turns, and the resistance is only 0.8 ohms, which can not only meet the design requirements but also improve the discharge speed, thereby speeding up the initial velocity of the projectile at the exit of the electromagnetic gun, increasing the effective range of the projectile.

4. Software Algorithm Design

4.1 Main Program Design

After the system is powered on and starts to work, the microcontroller starts to initialize each device and then enters the main function to start executing the subroutine for setting the coordinates, and then judges whether the virtual key is pressed, whether the target coordinates are set, and after the projectile is fired, it judges whether the projectile has passed through. Because the system functions are more complex, only the basic flow chart is given here, and the design of the main program flow chart is shown in Fig. 6

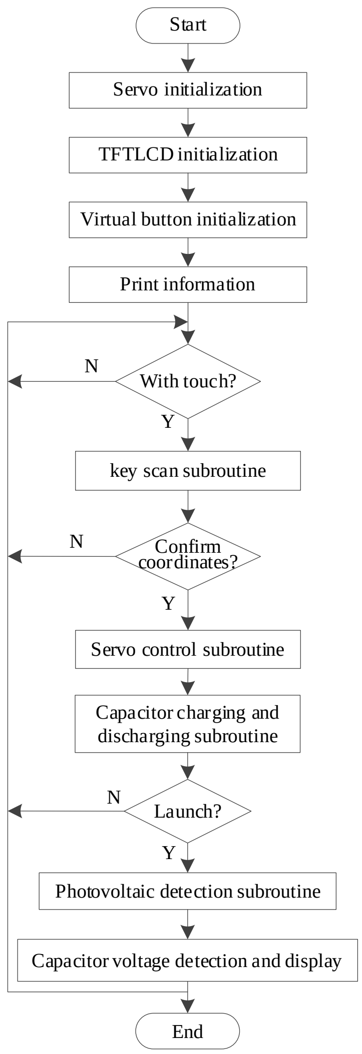

Figure6. *Flow chart of the main program*

4.2 Servo control program design

After inputting the coordinates, according to the calculated PWM pulse width, start to execute the servo control subroutine, and let the servo take the electromagnetic gun barrel to the designated position. The specific process is to first turn on the timer, output pulses with a period of 20ms, then count them in the overflow interrupt program, and control the angle of the steering gear according to the count value. The servo driver execution block diagram is shown in Fig. 7.

4.3 Capacitor charging and discharging subroutine

According to the voltage data collected and converted by the ADC, when the capacitor voltage is charged to the calculated value, the charging will be stopped immediately, and then the controller will control the firing of shells. The charging and discharging process of the energy storage capacitor is shown in Fig. 8.

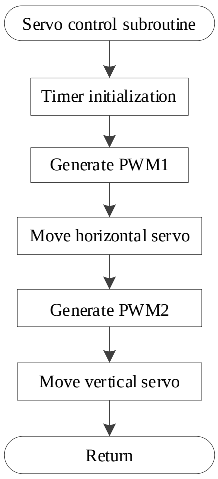

Figure7. *Execution block diagram of servo driver*

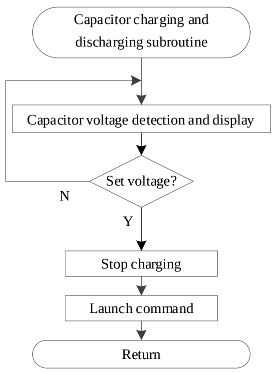

Figure8. *Execution block diagram of charging and discharging control*

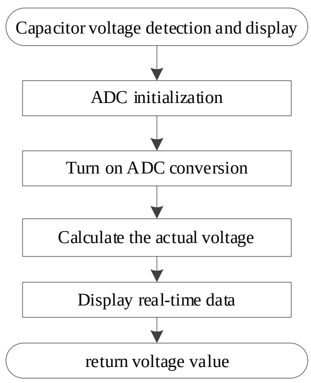

Figure9. *DC voltage detection execution block diagram*

4.4 DC voltage detection subroutine design

This program is mainly to obtain the voltage of the capacitor in real-time during the charging process. After the gimbal of the steering gear moves to a specific position, the MCU controls the charging module and turns on the peripheral ADC to collect the voltage value of the capacitor in real-time, and sends the converted value to the main function for comparison with the calculated data. After the energy storage is completed, it enters the launching subroutine. The process of DC voltage collection is shown in Fig. 9.

The real-time voltage in the microcontroller program is calculated by Eq. (6).

$$U = u_1 \times 137 \tag{6}$$

In Eq. (6), u1 is the collected analog voltage, and the data is feedback to the controller.

4.5 The virtual keyboard subroutines design

According to the design requirements, the software simulates the keyboard to collect the input target position. The main function of the program, it always detects whether a specific area of the keyboard is touched. After the input is completed, the required voltage data and gimbal pulse data are calculated according to the data size. The virtual keyboard process is shown in Fig. 10.

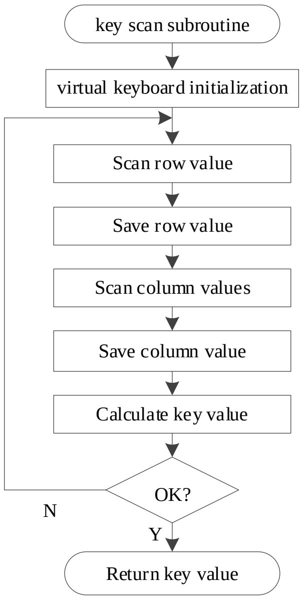

Figure10. *Virtual keyboard execution block diagram*

5. System Evaluation

After the circuit board is working normally, it is necessary to start a lot of experiments to collect enough data. The schematic diagram of the design test site is shown in Fig. 12 side view and Fig. 13 top view. There are two control schemes for bullet range, one is to adjust the elevation angle with a fixed voltage, but because the precision of the servo used is limited, this method cannot be used. The other method is to control the range of the shell by adjusting the fixed elevation angle to the capacitor voltage. The DC voltage is easy to collect, so it is decided to fix the elevation angle of the gun barrel and change the capacitor voltage scheme. After the control scheme is determined, the method of controlling variables can be used to determine the relationship of each parameter. First of all, determine the best position for the projectile placement. The initial position of the projectile has a great influence on the range. Therefore, the most suitable launching position must be determined first[20]. Based on the length of the shell's penetration into the coil, wecollect data of the penetration of the shell into the coil and the launch distance. Each data is tested 5 times. After removing the maximum and minimum values, the remaining three groups are averaged, and then the Excel software is used to draw a curve graph. From the results shown in the figure, it is easy to know that when the projectile extends into the coil by about $7mm$, the attractive force is the largest[21]. The actual result is shown in Fig. 14.

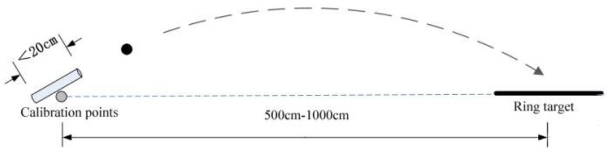

Figure12. *Side view of the system assessment site*

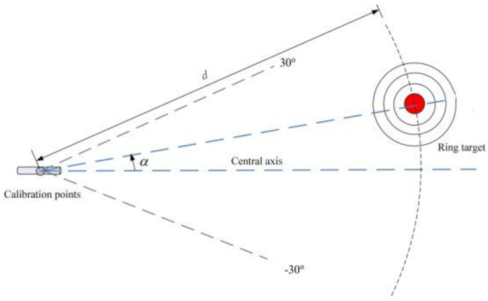

Figure13. *Top view of the system assessment site*

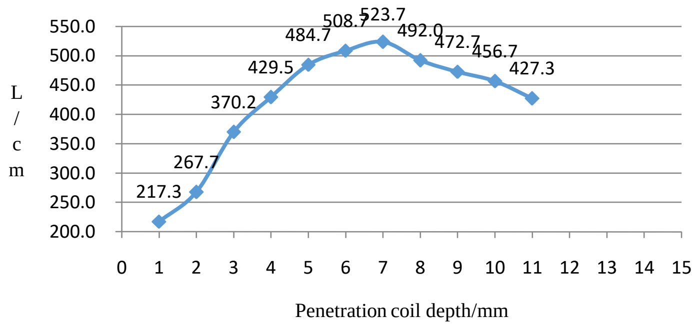

Figure14. *Relationship between initial position and distance*

Secondly, on the premise that the initial position of the shell has been determined, the best elevation position of the barrel can be determined. The specific idea is to give a capacitor voltage of 150V, change the elevation angle, collect the data, and process it into a graph in Excel. According to the curve trend in the graph, it is easy to get the longest range when the elevation angle is about 13 degrees. The actual data is shown in Fig. 15.

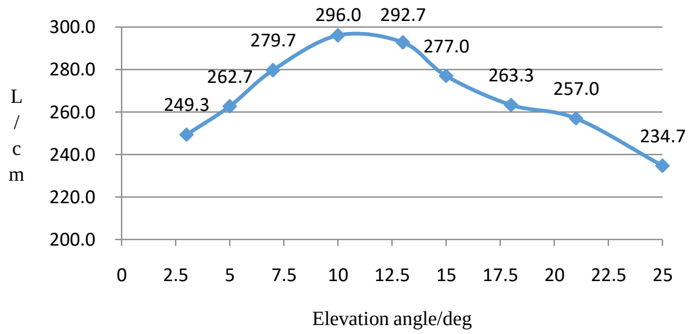

Figure15. *Relationship between elevation angle and distance*

Finally, based on the determined gun barrel elevation angle and the initial position of the projectile launch, the data collection of the voltage and the projectile launch distance was started. After collecting enough data[22], Matlab was used to fit the data. The results are shown in Fig. 16.

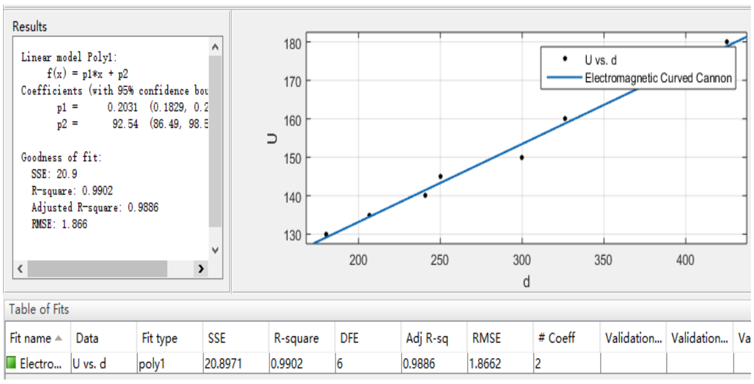

Fig16. *Fitting of voltage and distance*

The capacitor voltage can be calculated by fitting Eq. (7).

$$U = 0.2031d + 92.54 \tag{7}$$

In Eq. (7), U represents the capacitor voltage, and d represents the distance of the shell. The program according to the formula, and finally realize the precise strike by inputting the coordinates.

The average precision calculated according to the difference between the actual data and the input data can meet the design requirements. The actual distance and set distance data during the overall debugging are shown in Table 1.

Table1. *Comparison of set and actual distance data*

Set strike distance /cm	Emission voltage /V	Actual average distance /cm	Deviation /cm
500	194.1	499	1
550	204.2	548.5	1.5
600	214.4	599.5	0.5
650	224.6	648.8	1.2
700	234.3	700.5	0.5
750	244.9	750.8	0.8
800	255.0	801.3	1.3
850	265.2	851.5	1.5
900	275.3	900.7	0.7
950	285.5	951.3	1.3
1000	295.64	1001.2	1.2

After assessment, the system has realized the following functions: when the power supply is connected to the electromagnetic gun system, the whole system will start to execute the code in an orderly manner by pressing the switch. Execute the algorithm to obtain the corresponding servo movement signal, generate the corresponding PWM signal according to the calculated data to control the servo to move to the specified position, and then start to control the boost circuit to charge the energy storage capacitor according to the calculated capacitor voltage value. Calculate the value, stop charging and output the firing signal by the controller, and the shell hits the specified coordinate. At this point, one shot is completed, and the servo gimbal will automatically return to its position and wait for the next strike coordinate to be set. During this process, the corresponding voltage and angle information will be displayed on the LCD screen in real time.

6. Experimental Results

This set of simulated electromagnetic curved gun systems is mainly based on electromagnetic principles combined with microcontrollers to achieve control, and also simplifies the design difficulty of electromagnetic guns based on many predecessors. In this system, a new control algorithm and capacitor charging and discharging circuit are designed.The system has the functions of displaying the voltage at both ends of the capacitor in real-time on the LCD screen, the set object coordinate information, and controlling the gimbal. According to the input coordinates, it can automatically calculate the projectile trajectory, capacitor charging voltage and other relevant information, and control the barrel to adjust up and down, left and right to find a suitable firing position and launch immediately. The final small electromagnetic gun has the advantages of high precision, high power, high electromagnetic conversion efficiency, easy-to-obtain and cheap enough components, and convenient operation.

AUTHOR CONTRIBUTIONS

Conceptualization, S.Q.G.; methodology, S.Q.G.; software, W.Z.Z.; validation, S.Q.G., W.Z.Z.; formal analysis, Y.G.; investigation, S.Q.G.; resources, C.L.Z.; data curation, Y.G.; writing—original draft preparation, S.Q.G.; writing—review and editing, Z.W.W.; supervision, W.Z.Z.; project administration, Z.W.W.; funding acquisition, Z.W.W. All authors have read and agreed to the published version of the manuscript.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

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