Research and Development of Propane Pulse Acoustic Bird Repellent Cannons

Zheng Wang*, Chou Hu, Xinlei Zhang
Qingdao Campus of Naval Aviation University, Qingdao, Shandong, China
**Corresponding Author*

Abstract: Since the world's first bird strike incident, bird collisions have remained a major concern in aviation. With the growth of the aviation industry, the impact of bird strikes on flight safety has become increasingly prominent, emerging as a significant factor in aviation disasters. They cause substantial economic losses and threaten the lives of pilots, and are now recognized as major aviation disasters. Therefore, preventing bird strikes and ensuring flight safety have become urgent tasks facing the international aviation community. With continuous innovations in information technology and other fields, integrating airport bird strike prevention with bird control measures and modern technology to enhance the intelligence of bird strike prevention systems and reduce accident rates has become an urgent need for civil airports. In terms of design methodology, this paper first analyzes the practical requirements for airport bird control and the technical limitations of existing acoustic devices. It then proposes a single-sided 64-tube array solution featuring centralized loading and sequential triggering at the rear of the cannon. Utilizing propane pulse detonation as the acoustic source, the design establishes an integrated framework encompassing acoustics, mechanics, gas supply, ignition, control, safety, and operations for directional array design. By optimizing the barrel geometry and frequency band matching, designing anti-backfire and anti-explosion devices, and establishing a multi-level interlocking safety control and remote operation system, an integrated bird deterrent system has been developed that features high sound pressure, low noise dispersion, high loading efficiency, and high safety.

Keywords: Civil Airport; Bird Control; Propane Pulse; Centralized Loading; Sequential Triggering

1. Introduction

1.1 The Dangers of Bird Strikes and the Necessity of Prevention and Control

The world's first bird strike occurred in 1912 near the coast of Long Beach, California, USA. Since then, bird strikes have become a major concern within the aviation industry [1].With the development of the aviation industry, the impact force of aircraft in flight is immense, and collisions with birds can cause fatal damage. The impact of bird strikes on aviation safety has significantly intensified, becoming one of the primary factors contributing to aircraft accidents. The industry refers to such incidents as “bird strikes”. Bird strikes in aviation are infrequent but have extremely severe consequences. Their risk is influenced by multiple factors, including habitat types surrounding airports, migratory bird routes, meteorological conditions, and operational periods. These frequent and hazardous incidents can cause significant economic losses and casualties, disrupting civil aviation traffic or military flight training missions [2].Currently, approximately 10,000 such incidents occur globally each year. The International Air Transport Association has classified bird strikes as Category A aviation disasters. Consequently, experts and scholars worldwide have been striving to develop highly feasible and adaptable bird deterrence solutions using cutting-edge technological methods to maximize aircraft safety [3].Analysis of Bird Strike Incidence Trends in China's Civil Aviation Sector from 2014 to 2025 is shown in Figure 1.

1.2 Bird Strike Risk and Existing Bird Deterrent Technologies

The area surrounding the airport is predominantly grassland, where abundant food sources attract large numbers of birds, increasing the risk of bird strikes. Therefore, installing bird deterrent devices within the airport perimeter is an effective measure to prevent bird strike incidents.

Currently, the primary bird deterrence methods employed at civil airports fall into four categories: Acoustic deterrence: Personnel play recordings of bird predators or any sounds that cause extreme discomfort to birds; Visual deterrence: Visual intimidation using biomimetic eagle eyes, lasers, reflective films, or dynamic lighting; Biological deterrence: Employing natural predators like falcons and raptors to create ecological deterrence; Intelligent bird control systems: Integrating drones, radar, and AI recognition for automated patrol and deterrence [4].

Traditional real-time bird deterrent devices rely on methods such as directional sound waves to repel birds, but birds easily adapt to them. Moreover, over 90% of bird strike incidents occur within the 300-500m airspace, making bird strikes in the low-to-medium altitude zones surrounding airports the primary threat to the safe takeoff and landing of large aircraft. However, conventional straight-tube bird repellent cannons cannot project projectiles to the 350-meter altitude range where bird strikes are most frequent. Bird strikes represent severe accidents caused by collisions between birds and high-speed aircraft, and proactive prevention methods for bird strikes in the low-to-medium altitude zones near airports remain inadequate. Therefore, developing bird repellent devices that meet airport requirements for high-altitude bird control and counteract bird adaptation is essential for airport safety [5].

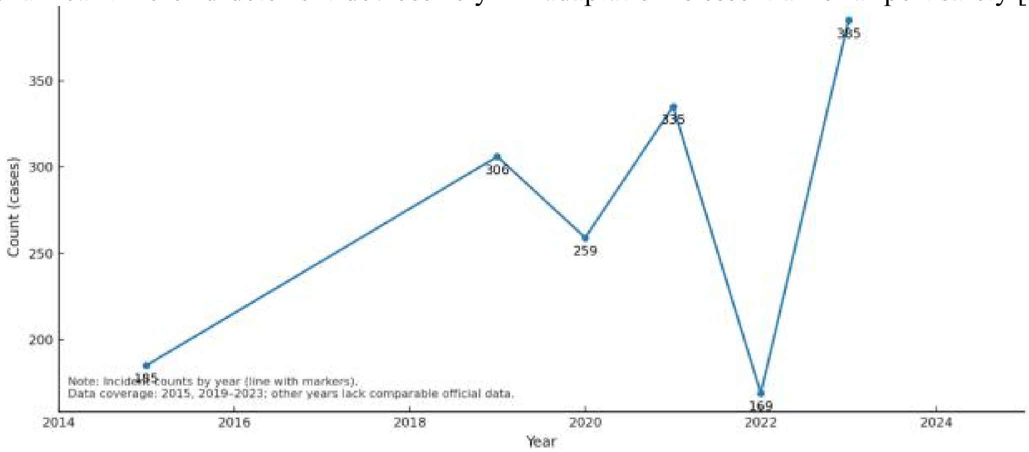

Figure 1. Analysis of Bird Strike Incidence Trends in China's Civil Aviation Sector from 2014 to 2025

2. System Design Objectives and Constraints

The titanium thunder cannons currently used at airports typically consist of a two-stage “launch-explosion” mechanism: First, the primary propellant ignites to generate thrust, propelling the explosive device into the air. It then detonates mid-air to achieve bird deterrence. The launch propulsion is derived from the propellant charge within the projectile. Existing titanium thunder cannons have revealed numerous operational issues: cumbersome shell loading procedures and limited single-load capacity result in delayed bird-deterrent responses; inadequate equipment protection significantly impacts performance under weather conditions; and operational inconveniences hinder overall user experience and efficiency.

With technological advancements and evolving industry demands, establishing an integrated, intelligent bird strike prevention system encompassing detection, identification, and deterrence has become an inevitable trend. To enhance the industrial chain of this system, there is an urgent need for complementary intelligent bird deterrent equipment: capable of fully automated operation without human intervention, capable of connecting to online command and dispatch terminals and control centers, and able to coordinate operations under unified intelligent control to achieve precise and efficient bird deterrence [6].

2.1 Performance and Functional Objectives

The primary objective of the system design is to achieve a balance between bird deterrence effectiveness and safety. Key performance indicator (KPI) include:

(1) Repellent success rate ≥85%, effectively

reducing bird gatherings;
(2) Response time <10 seconds, enabling rapid dispersal;
(3) System availability ≥ 99.5%, ensuring high reliability;
(4) Single-cycle full-array loading time ≤ 120 seconds;
(5) Noise levels at the boundary shall be controlled below 65 dB(A).
These indicators were established by integrating the operational characteristics of major domestic hub airports with the frequency requirements for bird control operations.

2.2 Security and Compliance Constraints

The design complies with multiple national and industry standards:<GB 50058 Code for Design of Electrical Installations in Explosive and Fire Hazardous Environments>,<GB 22337-2008 Environmental Noise Emission Standard for Social Life>, and<GB 50057 Code for Lightning Protection Design of Buildings>.
Therefore, the equipment must incorporate safety designs such as explosion-proof, lightning-proof, accidental-touch-proof, and anti-static features, along with automatic pressure relief and emergency shutdown mechanisms. Additionally, the equipment interfaces with the ATC flight scheduling system to automatically disable transmissions when flights enter quiet windows, ensuring no acoustic interference.

3. System Master Plan

3.1 System Architecture Design

The system adopts a six-layer decoupled architecture comprising perception, decision-making, execution, retrofit modules, interconnection, and operation & maintenance. It achieves loose coupling integration and on-demand scalability through standardized interfaces and a message bus. The perception layer encompasses sensors for atmospheric pressure, temperature, humidity, door contacts, infrared beams, combustible gas leaks, wind speed and direction, precipitation, and perimeter noise, providing the foundational data for strategy formulation and interlocking. The decision layer employs a PLC-based cooperative state machine and strategy engine to execute self-checks, interlocks, degradation, and trigger sequence generation. It supports parametric configurations including group interleaving, intra-group randomization, cooling ratio allocation, and time window constraints, while retaining local offline strategies. The execution layer comprises a 64-tube array, igniter and solenoid valve matrix, main gas line and distribution manifold, check valves and flame arresters, forced ventilation, and zone cooling. It supports single-tube addressing and vectorized triggering, ensuring high instantaneous sound pressure output while maintaining main lobe directionality and side lobe suppression [7].The rear compartment provides centralized ammunition loading and gas supply interfaces, utilizing quick-change rails and positioning brackets. Integrated with RFID technology, it enables ammunition position counting, batch traceability, and real-time visualization of remaining quantities, reducing downtime for resupply. The coordination layer interfaces with air traffic control flight plans, ramp scheduling, and noise monitoring platforms, supporting synchronization with noise abatement windows and restricted firing zones. Communication prioritizes Ethernet + OPC UA, with CAN gateway compatibility for legacy equipment. The operations layer offers local HMI and remote platforms: operational/alarm dashboards, log auditing, configuration deployment/rollback, health assessments, consumable lifespan prediction, version upgrades, and permission management. The power supply side incorporates UPS, lightning protection, and critical channel isolation, with enclosures meeting outdoor industrial-grade IP ratings and weather resistance requirements.

3.2 Functional Workflow

The system operates in a closed-loop state machine following the sequence: "Sensing Wake-up → Self-Test and Chain Establishment → Arm and Standby → Sequence Execution → Cooling and Reset → Audit and Archiving." Following automatic or manual triggering, the controller performs self-checks on pressure, leakage, temperature, door magnetic switches, communication, and power redundancy while acquiring mute and firing inhibition constraints. Upon passing these checks, it enters the ready state, inspects the availability of 64 warhead positions and igniters, and generates a schedule containing grouping sequence, intra-group randomization, trigger duration, interval, and cooling ratio [8].During the execution phase, ignition and valve control are performed on the target sector while telemetry data is collected, including pressure recovery curves, ambient temperature, noise main lobe and boundary violations, valve response, and ignition success rates. When an aircraft makes an unplanned approach or noise approaches threshold levels, the strategy engine immediately reduces power, pauses, or disables firing, recording the cause code. Following sequence completion, the system enters cooling reset with regional ventilation and temperature control activated as needed. The rear-loading compartment updates munitions counts and issues resupply alerts. The entire process is time-stamped via PTP and recorded in an immutable event chain for audit and effectiveness evaluation. Should any step encounter anomalies, the system prioritizes switching to safe shutdown mode, ensuring minimum essential capability is maintained within compliance parameters.

3.3 Safety Interlock System

Interlocking adheres to the principle of "multi-dimensional sensing + dual-channel criteria + fail-safe operation," encompassing six core logic functions: - Door magnetic switch failure prevents firing and locates door position; - Infrared beam obstruction immediately halts firing with audible/visual alerts; - Gas pressure exceeding limits triggers derating first, followed by main valve closure and forced venting upon persistent abnormality; electrical compartment temperature triggers tiered cooling and shutdown; external link failure downgrades to local whitelist and disables high-risk actions; all emissions blocked during flight silence windows [9].The hardware chain connects directly to the execution layer, while the software chain handles hierarchical alerts and auditing, adopting the more conservative action when discrepancies arise. The system periodically performs door sensor cycles, beam obstruction checks, pressure/temperature calibration, chain break drills, and silent meter verification. All events are logged before resolution to ensure replayability, accountability, and verifiability.

4. Structural Composition

4.1 Barrel and Array Structure Design

Each barrel is designed based on the principle of a quarter-wavelength resonant cavity, with its fundamental frequency

$$f=\frac{c}{4L_{eff}} \quad (1)$$

Where c is the speed of sound and L_{eff} is the effective length; a bell section is added at the mouth to match the acoustic impedance of air and enhance sound energy radiation efficiency. Simultaneously, a Helmholtz auxiliary cavity is embedded within the main cavity to strengthen sound energy focusing and broaden the frequency band, concentrating the output frequency within the 2.5-3.0kHz range. This frequency band corresponds to the sensitive range of avian hearing, enabling the induction of a significant stress response without causing harm [10,11].

The array employs an 8×8 single-sided layout with a 0.2m spacing between elements. Sound field simulations indicate a main lobe half-power angle of approximately 15° and side lobe suppression of about 12dB, enabling the formation of a highly directional main impact sound lobe. Combined with grouped triggering and micro-phase difference control between elements, the main lobe can undergo fine-level directional adjustments within ±15°, achieving targeted coverage of the designated area [12].Design of gun barrel and array structure is shown in Figure 2.

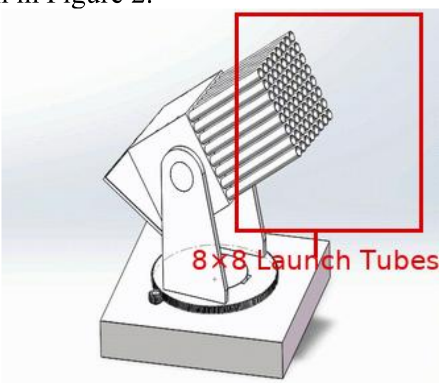

Figure 2. Design of Gun Barrel and Array Structure

4.2 Rear Unified Ammunition Compartment Design

The ammunition compartment, situated at the rear of the turret, serves as the critical unit for achieving high-efficiency operations. The compartment features a heat-resistant metal frame and flame-retardant composite panel enclosure, with eight independent feed tray channels internally configured—each tray corresponding to eight gun barrels. The compartment door employs a dual-locking mechanism combining electromagnetic locks with mechanical linkage, ensuring both sealing integrity and operational reliability [13].The material frame features a drawer-style quick-change design. After loading, it automatically aligns and locks with the chamber via positioning pins. During shutdown venting, the system automatically releases the door lock, allowing operators to replace the material frame. The interface incorporates a foolproof mechanism to prevent reverse insertion or misinstallation, reducing downtime and improving operational cycle times.

To ensure safety, the chamber is equipped with multiple monitoring systems including dual door magnetic sensors, infrared beam curtains, gas leak detectors, and temperature sensors. Should any safety condition fail, the PLC logic automatically prevents ignition and maintains door lock closure. Simultaneously, LED indicators and voice prompts within the chamber provide alerts and guidance, forming a closed-loop mechanism of "detection-interlock-alarm" [14].The rear part is designed with a unified ammunition compartment is shown in Figure 3.

Figure 3. The Rear Part is Designed with a Unified Ammunition Compartment

4.3 Fuel Supply and Ignition System

To ensure the long-term stable operation of bird-scaring cannons under continuous feeding, ignition, and firing conditions, this system adopts an integrated approach of "isobaric stable supply + non-contact ignition" for gas supply and ignition. The primary gas source undergoes pressure reduction and stabilization before entering the main manifold. Gas is then distributed through branch lines to evenly supply all 64 cannon barrels. After comparative testing of high-frequency pulse, arc, and laser ignition methods, laser ignition was selected. Testing demonstrated that high-frequency pulse ignition requires close proximity, involves complex ignition mechanism design, and achieves lower success rates than laser ignition. Laser ignition, precisely triggered by the controller to generate an energy pulse from the laser head, instantly ignites the fuse. It offers advantages including simplified structure, easy maintenance, controllable ignition timing, high ignition accuracy and stability, high efficiency, excellent safety, long service life, pollution-free operation, and support for remote control. This makes it suitable for high-reliability demands in civilian applications [15].

The gas supply system consists of a main cylinder, pressure reducer, main manifold, and eight branch lines, maintaining a stable working pressure of 0.45 MPa. Each branch line evenly distributes gas to 64 terminal lines. Gas connections utilize ferrule seals and incorporate check valves to prevent backflow. To ensure synchronized discharge across multiple lines, branch line length consistency is controlled within a 1% tolerance. The ignition system employs independent ignition modules grouped by array, with a single ignition delay not exceeding 20ms. Launching utilizes a grouped sequential firing strategy with 150ms intervals between groups, effectively preventing cross-ignition and backfire while reducing the single-impulse impact of transient pressure waves on structures and acoustic fields [16].The system automatically records cabin temperature changes and combustion duration after each trigger, for health monitoring and maintenance decision-making.

For safety protection, flame arresters are installed at the gas supply end, each branch end, and the barrel end. The flame arresting elements feature a composite structure of metal mesh and ceramic cores to enhance flame arresting reliability and durability. An automatic pressure relief valve is positioned at the top of the chamber. It automatically opens to vent when internal pressure exceeds 0.6MPa, preventing overpressure risks [17].The ignition assembly is mounted on a dedicated frame and reliably isolated from the firing chamber via a sealed glass plate and gasket. This design prevents contamination of the laser head by residues and dust while withstanding the destructive impact of compressed gas. Positioned at the lower end of the barrel, the assembly allows for easy installation, removal, and focusing adjustments. This facilitates on-demand modification of parameters such as working power, focal length, and operating distance to meet reliable ignition requirements across diverse scenarios. Overall structure of bird repelling gun is shown in

Figure 4.

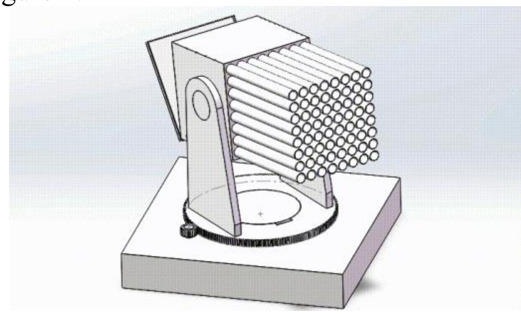

Figure 4. Overall Structure of Bird Repelling Gun

4.4 Control System

4.4.1 System solution framework

Electrical equipment selection should prioritize versatility, reliability, and widespread availability to meet the mass production requirements of bird deterrent devices. The control system employs a PLC as the primary control component, enabling interactive control with controllers, detection elements, and display devices. It supports remote transmission control or automated transmission through communication with a host computer. System Block Diagram is shown in Figure 5.

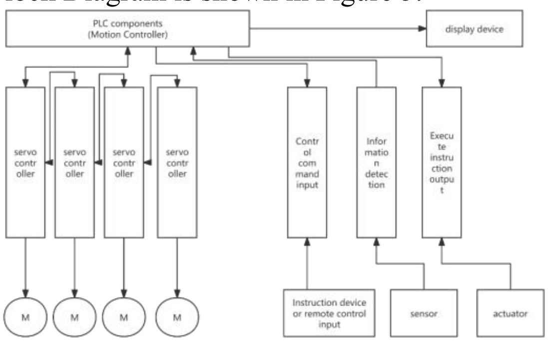

Figure 5. System Block Diagram

4.4.2 System control process

To design an appropriate system control process, it is necessary to first analyze the overall operation of the equipment. The operational sequence of the bird deterrent device is divided into two categories: real-time controlled actions and automatic detection-driven actions. The former primarily involves bird deterrent projectile launch operations, such as launch position and single-shot firing commands; the latter encompasses compressed air supply, projectile feeding, and the continuous execution of actuators during the launch process. To achieve effective control, the control system must comprehensively process information and data including the device's current status, the number of available bird repellent projectiles, firing position parameters, input control commands, and output displays [18].

4.4.3 System programming

The program consists of two parts: event-driven programs and periodic programs. Event-driven programs primarily relate to servo motor control, including servo motor enable, brake release, real-time jogging per commands, and running to specified positions based on preset settings. When the equipment receives a real-time motion command, the corresponding servo axis must sequentially complete enable, brake release, and command-based operation. When the real-time command stops, the servo axis must execute procedures such as stopping operation, closing the brake, and disabling enable. System Control Flowchartis shown in Figure 6.

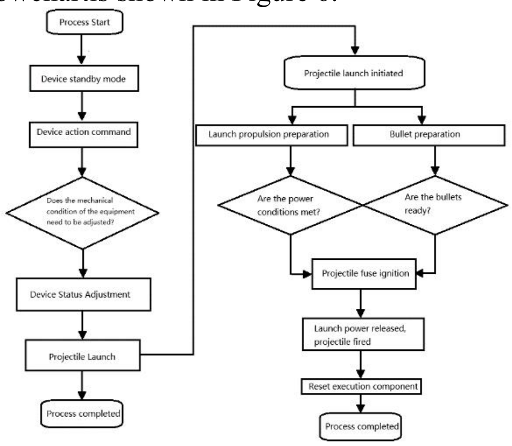

Figure 6. System Control Flowchart

Cyclic programs primarily serve as flow control instructions for equipment operations, encompassing detection, execution control of motion components, and display functions. When the equipment is in standby mode, the program continuously executes an empty loop to maintain the current state. Upon detecting changes in sensors or command inputs, the program executes corresponding output actions based on updated conditions within its operational cycle, thereby altering the equipment's state [19].

5. Conclusion

Research findings indicate that arrayed sound sources, through rational control of array spacing and phase, form a highly concentrated and stable main lobe. This alters the traditional “spherical diffusion” energy distribution of single-tube systems, simultaneously enhancing both the effective stimulation rate per unit sound pressure for birds and long-range coverage. Concurrently, the robust suppression of side lobes significantly reduces noise spill outside the field boundary, providing technical support for compliance with noise regulations. To delay behavioral adaptation to fixed rhythms, the system employs grouped interleaving with random triggering within groups. This creates nonlinear temporal and spatial perturbations in the sound waves, weakening prediction and habituation effects. Consequently, it maintains high and stable deterrence efficiency and persistence during continuous operation under high-density flight schedules.

At the ecological and compliance level, main lobe directional control combined with real-time noise monitoring deposits acoustic energy within target sectors. This integrates with flight noise reduction strategies to enable automatic power reduction or transmission suppression, balancing flight safety with the acoustic environment of surrounding communities. This approach can also be applied to other noise-sensitive airport operations. For engineering implementation, the system's modular design and standardized interfaces facilitate rapid replication and deployment across hub, regional, and general aviation airports. When integrated with directional speakers and drone-based bird dispersal, it forms a layered, complementary bird control system that enhances coverage and intelligence. Future evolution toward sound source recognition, target identification, and automated strategy scheduling promises higher levels of unmanned, closed-loop bird control management.

Although the current performance is satisfactory, there remains room for improvement: Rhythm randomization still relies primarily on preset rules, and future work will explore AI adaptive scheduling based on environmental context and target responses; array pointing adjustments still require manual intervention, and plans are underway to enhance flexibility and response speed through electrically controlled steering; long-term stability under extreme weather conditions and maintenance costs still require empirical evaluation. Future work will focus on developing intelligent closed-loop strategies, implementing electronic control for actuators, and enhancing adaptability in complex environments, ultimately forming an integrated upgrade solution spanning perception, decision-making, and execution.

References

[1] Xie, L., Wang, K., Li, M., et al. Research on Test Methods for Equipment Safety. Electronic Product Reliability and Environmental Testing, 2024, 42(04): 45–50. DOI: CNKI:SUN:DZKH.0.2024-04-009.

[2] Yu, H. Research on Security Risk Prevention in the Security Screening at H Airport. Guangxi Normal University, 2023. DOI:10.27036/d.cnki.ggxsu.2023.001521.

[3] Wang, N., Si, L., Li, H., et al. Design of a Wireless Distributed Bird-Repelling System for Airport Security. Software, 2025, 46(01): 125–128. DOI: CNKI:SUN:RJZZ.0.2025-01-026.

[4] Wang, M. Task Allocation and Path Planning for a Multi-UAV Cooperative Airport Bird-Repelling System. Nanjing University of Aeronautics and Astronautics, 2019. DOI:10.27239/d.cnki.gnhhu.2019.000197.

[5] Shen, J. Research on Directed Expulsion Technology for an Intelligent Bird-Repelling System with Multiple Energy States. Yancheng Institute of Technology, 2024. DOI:10.44381/d.cnki.gycit.2024.000097.

[6] Zheng, Q. Airport Intelligent Bird-Repelling Methods Based on Biological Features. Intelligent IoT Technology, 2025, 57(01): 48–51. DOI:10.26921/j.cnki.2096-6059.2025.01.010.

[7] Jiang, B., Lai, J., Yuan, C., et al. A Review of Key Technologies for Fault-Tolerant Navigation and Control of Low-Altitude Aircraft. Navigation, Positioning and Timing, 2025, 12(05): 1–21. DOI:10.19306/j.cnki.2095-8110.2025.05.001.

[8] Fan, S., Wu, X., Fan, J. Design of a Control System for an Intelligent Assembly Line Based on PLC and Robot Collaboration. Digital Technology and Application, 2025, 43(09): 235–237. DOI: CNKI:SUN:SZJT.0.2025-09-073.

[9] Yang, S. Research on Perimeter Intrusion Prevention Technology for Intelligent Buildings Supported by Video Surveillance. China New Technologies and New Products, 2025, (19): 137–139. DOI:10.13612/j.cnki.cntp.2025.19.037.

[10] Gao, H., Yang, X., Zhou, B., et al. Coupling-Induced Microwave Transparency

in Quarter-Wavelength Superconducting Resonators. Acta Physica Sinica, 2022, 71(06): 337–345.

[11] Chen, J., Wang, X., Liu, B., et al. Functionalization and Protection of Rail Surfaces for Electromagnetic Railguns. Ordnance Material Science and Engineering, 2022, 45(02): 134–140. DOI:10.14024/j.cnki.1004-244x.20220124.011.

[12] Gao, H., Cao, E. Applications and Development of Ultrasonic Phased Array Inspection Technology. Mechanical Engineer, 1–8 [2025-10-19]. Available at: https://link.cnki.net/urlid/23.1196.TH.20251016.1348.002.

[13] Zhang, S., Li, X. Study on a Lockout Logic Method and Device for Measurement-and-Control Anti-Misoperation Based on Visual Verification// Proceedings of the 2022 Excellent Papers of the Zhejiang Society for Electrical Engineering. State Grid Zhejiang Electric Power Co., Ltd., Ningbo Power Supply Company, 2023: 194–198. DOI:10.26914/c.cnkihy.2023.040324

[14] Xu, G., Wu, Y., Xu, Q., et al. Design of an Electrical Safety Detection and Warning Device Based on PLC Technology. Electrical Technology and Economy, 2025, (09): 315–317. DOI: CNKI:SUN:DGWZ.0.2025-09-094.

[15] Zhang, B., Liu, W., Song, Q., et al. Laser Ignition of Fuze Compositions. Sci-Tech Innovation and Productivity, 2022, (07): 98–100. DOI: CNKI:SUN:TAIY.0.2022-07-029.

[16] Jiang, S. Theoretical Study and Numerical Simulation of the In-Bore Dispersion Group Model for a Large-Caliber Balanced Gun. Nanjing University of Science and Technology, 2017.

[17] Gong, R. Selection of Flame Arresters. Chemical Equipment & Pipeline, 2002, (03): 5–7+3. DOI: CNKI:SUN:HGSB.0.2002-03-000.

[18] Ma, L. Study of an Automatic Overcurrent Detection Test Device for Low-Voltage Electrical Products. China New Technologies and New Products, 2025, (13): 68–70. DOI:10.13612/j.cnki.cntp.2025.13.006

[19] Liu, C., Li, M., Zhang, X., et al. Development and Application of a Compressed-Air-Powered Bird-Repelling Device. China Heavy Equipment, 2025, (01): 57–61. DOI:10.14145/j.cnki.51-1702/th.2025.01.010.