# Design of an Automatic Sorting and Punching Device for Cadre Personnel Files

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**ABSTRACT** To address low manual efficiency and punching inaccuracies an integrated intelligent device has been designed to automate the sorting and punching of cadre personnel files in accordance with national document revision standards. The device adopts an integrated architecture of "vibration blowing collaborative sorting+infrared precision detection+ hydraulic driven punching", consisting of a mechanical execution system (vibration module, blowing module, punching module), an automatic detection system, and an intelligent control system.Experimental results on three major sample groups demonstrate that the proposed device achieves an average alignment accuracy of 99.2%, a punching position error $\leq \pm 0.3$mm, and a document damage rate below 0.1%, fully meeting the technical standards of the Central Organization Department. It realizes the integration of sorting, detection, and punching, providing a reliable and efficient solution for intelligent archive management. The infrared detection and PLC control process also requires attention to electromagnetic compatibility under motor-driven vibration and hydraulic actuation.

**INDEX TERMS** automated sorting,precision punching,infrared detection,mechatronic control, electromagnetic compatibility

## I. INTRODUCTION

### A. RESEARCH BACKGROUND

CADRE personnel files constitute a vital resource for the Party's governance, containing core information such as an individual cadre's political integrity, work history, and performance evaluations. They serve as the primary basis for cadre selection and appointment, rank promotion, and oversight management [1,2]. With the advancement of nationwide special reviews and digitization initiatives for cadre personnel files, the workload for file organization has surged exponentially. According to statistics from the Organization Department of the CPC Central Committee, grassroots archive management departments nationwide processed over 12 million cadre personnel files annually in 2023, with the organization and punching stages accounting for more than 60% of the total workload [3-7].

### B. CURRENT STATE OF DOMESTIC AND INTERNATIONAL RESEARCH

#### 1) Research on File Sorting Equipment

Overseas development of file sorting equipment began earlier, focusing on automation and standardization: Fellowes GmbH's AutoAlign series automatic paper aligners utilize airflow disturbance combined with highfrequency vibration to align papers with an accuracy of $\pm 0.5$mm. However, they lack integrated punching functionality, requiring manual transfer to punching equipment after sorting, which risks secondary misalignment [8].

Japan's Kodak developed an archival sorting platform using vacuum suction to secure paper edges, accommodating multiple paper sizes. However, its bulky size (occupying over 2m2) and high cost (over ¥100,000 per unit) hinder widespread adoption in grassroots archival management departments [9].

Domestic research focuses on single-function optimization and cost control:

Lü Cuiwei et al. [10] designed an archival sorting workbench that aligns A4 paper using fixed guides and manual push plates. However, it requires repeated manual adjustments, taking approximately 15 seconds per document, resulting in low efficiency;

Dongguan Baoxin Machinery Equipment Co., Ltd.'s paper vibration machine (Patent No.: CN201620222514.6) [11] utilizes an eccentric wheel vibration motor to eliminate static electricity and assist paper alignment. However, it lacks an automatic detection module, requiring manual assessment of sorting results and preventing closed-loop process control;

The paper sorting device designed by Qiqihar Engineering College (Patent No.: CN202022183684.7) [12] optimizes alignment through the combined action of brushes and airflow. However, it is only suitable for new paper and has poor adaptability for wrinkled, thin, or brittle old archives.

Existing sorting equipment generally lacks the multi-axis coordination found in modern machinery, resulting in single functionality and an inability to meet the integrated "sorting-punching" require-ments for cadre personnel archives. By adopting the multi-axis collaborative positioning control and auto-mated tension control of precision processing, this system overcomes low automation levels to ensure archival punching standards are met with industrial-grade consistency.

2) Research on ArchivePunchingandBindingEquipment

Overseas punching equipment prioritizes precision and safety:

GBC Corporation's BindMate series electric punches utilize stepper motor drives, controlling punching position error to ±0.5mm. However, manually positioning organized archives precisely on the reference line is required, and it cannot automatically adapt to varying archive specifications [13].

Switzerland's Leitz Ideal series multifunctional binding machines support adjustable hole spacing and diameter. However, they lack specialized dies for the "three-hole standard" of cadre personnel files, requiring manual parameter adjustments and complex operation [14].

Domestic research emphasizes localized adaptation and practicality:

Luoyang Institute of Technology's hand-operated paper punch (Patent No.: CN202121192286.X) [15] features a simple structure and low cost (less than 500 yuan per unit), but relies on manual force and can only punch 10-15 sheets at a time, resulting in low efficiency;

Shandong Yubo Jiuzhou Technology Co., Ltd.'s personnel file binding machine (Patent No.: CN202120546636.1) [16] optimizes the three-hole synchronous punching mold for A4 paper standards. However, it fails to address automatic file alignment, requiring manual positioning before punching, which still leads to accuracy fluctuations;

The archive punching and binding machine developed by Xingtai Vocational and Technical College (Patent No.: CN201620429646.6) [17] integrates punching and binding functions. However, manual assistance is still required during the sorting stage, preventing full process automation.

The core shortcoming of existing punching equipment lies in its "disconnection from the sorting process," failing to achieve seamless transition from document alignment to punching. This vulnerability to manual handling errors or positioning deviations oft en leads to quality issues.

3) Research onEquipmentAutomaticDetectionand ControlSystems

The application of automatic detection technology in document processing is expanding:

Overseas researchers employ machine vision technology (e.g., CCD cameras + edge detection algorithms) to achieve paper alignment accuracy detection with precision up to ±0.2mm. However, the algorithms are complex (requiring training convolutional neural network models) and have slow response times (single-frame processing exceeding 100ms), making them unsuitable for realtime processing of bulk archives [18]; In domestic research, infrared sensors are widely used for "paper presence detection," such as in Zhang Lulu's archival binding machine design (Patent No.: CN202020301043.4) [19]. A single infrared sensor determines whether archives are properly positioned, but cannot detect alignment accuracy, still requiring manual intervention;

Huawei's "dual-infrared cross-detection solution" [20] uses signal superposition from two sensors to determine paper edge positions, reducing response time to under 20ms. However, it lacks customized design for the "bottom-left alignment" standard of cadre personnel archives.

Regarding control systems, PLCs (Programmable Logic Controllers) are widely used globally for equipment coordination. However, traditional PLC control suffers from "inflexible parameter adjustment and poor human-machine interaction," making it difficult to adapt to processing archives of varying thicknesses and materials.

### C. RESEARCH GAPS

Current research faces three core gaps:

1. Insufficient functional integration: Existing equipment typically offers single functions like "sorting" or "punching," lacking integrated design. Manual transfer between processes is required, increasing the risk of secondary errors.

2. Difficulty balancing precision and efficiency: High-precision equipment (e.g., machine vision solutions) suffers from low efficiency and high costs, while high-efficiency equipment (e.g., traditional paper vibrators) lacks sufficient precision, making it challenging to meet the standard requirements for cadre personnel archives.

3. Limited adaptability and safety: Inadequate handling capabilities for special archives like aged, fragile, or creased materials, coupled with absent damage-prevention mechanisms, fail to meet "permanent preservation" security requirements.

Therefore, there is an urgent need to develop an automated sorting and punching device for cadre personnel archives that integrates the high-precision interlacing logic of modern machinery to enable multi-functional standardization and intelligent adaptability. By applying the tension-controlled feeding and fiber-alignment precision characteristic of advanced weaving systems, this device fills existing research gaps and en-sures the delicate structural integrity of archival documents during high-speed processing.

### D. RESEARCH QUESTIONS AND INNOVATION POINTS

1) Core Research Questions

1. How to design a "vibration-blowing" coordinated sorting mechanism that automatically aligns cadre personnel files of varying materials and conditions along their lower left edges while preventing damage?

2. How to construct a precise, rapid automatic detection system that real-time assesses file alignment status, ensuring

pre-punching alignment accuracy meets standards (error $\leq$0.5mm)?

3. How to optimize the hole-punching drive mechanism and mold design to achieve synchronized three-hole punching with positional error controlled within $\pm$0.3mm, meeting the technical standards of the Central Organization Department?

4. How to design an intelligent control system to realize fully automated linkage of the "sorting-detectionpunching" process while maintaining adjustable parameters to accommodate different file specifications?

#### 2) Research Innovations

1. Proposed "Vibration-Blowing-Gravity" Collaborative Sorting Mechanism: Utilizes an eccentric wheel vibration motor (50Hz frequency, 0.8mm amplitude) in tandem with a dual-sided symmetrical blowing mechanism (1.2m/s air velocity) to eliminate paper static electricity; Combined with the archive's own gravity and the left-lower work surface stop plate, this achieves automatic alignment for archives of different materials (new paper, photocopies, thin/fragile archives) with an alignment accuracy of 99.2%.

2. Dual Infrared Precision Detection System: Two infrared sensors (detection range 5mm, response time 15ms) are positioned at the lower left edge of the work surface. These sensors independently monitor alignment of the paper's left and bottom edges. The punching process initiates only when both sensors trigger simultaneously, eliminating human judgment errors and achieving 100% detection accuracy.

3. Developed a hydraulically driven triple-hole synchronous punching mechanism: Utilizes a single hydraulic cylinder (operating pressure 0.8MPa, stroke 30mm) to drive the transmission plate, synchronously operating three specialized drill bits (hole diameter 5mm, hardness HRC60). Precise alignment between the mold positioning groove and the workbench reference line ensures punching positional error $\leq\pm$0.3mm, fully compliant with the standards set by the Organization Department of the CPC Central Committee.

### E. RESEARCH SIGNIFICANCE

#### 1) Theoretical Significance

1. Enriches archival management equipment design theory by proposing a "multi-physics field coordination (vibration, airflow, gravity)" archival organization method, offering novel technical approaches for automatic alignment of non-rigid materials (paper).

2. Refines the integrated "detection-drive-control" architecture for archival processing equipment, establishing technical standards and evaluation systems for automated sorting and punching of cadre personnel archives, providing theoretical references for similar equipment development.

#### 2) Practical Significance

1. Enhanced Efficiency: Reduces processing time per batch (100 documents) from 28.6 minutes manually to 4.2 minutes, achieving a 6.8-fold efficiency increase and alleviating workload pressure on grassroots archive management departments;

2. Quality Assurance: Achieved 99.2% alignment accuracy, with punching position error $\leq\pm$0.3mm. Document damage rate reduced to below 0.1%, meeting the Central Organization Department's archival organization standards and improving the standardized process of archive management.

3. Cost Reduction: Unit equipment cost controlled below ¥18,000. Daily per-capita processing capacity increased to over 1,200 documents, yielding annual labor cost savings of approximately ¥60,000 per employee.

4. Drive Transformation: Provide front-end standardized processing equipment for digitizing cadre personnel archives, facilitating the transition from manual operations to intelligent equipment in archive management, with broad applicability.

## II. THEORETICAL AND TECHNICAL FOUNDATIONS

### A. CORE THEORETICAL SUPPORT

#### 1) Paper Mechanics and Electrostatic Elimination Theory

As a non-rigid material, paper handling involves mechanical equilibrium and electrostatic elimination:

1. Mechanical Properties of Paper Stacks: Friction exists between stacked papers (primarily from static electricity and surface roughness). When inertial forces generated by vibration exceed friction, papers move along the path of least resistance (toward the baffle's limiting direction), achieving alignment;

2. Electrostatic Elimination Principle: Friction-generated static voltage on paper can exceed 1000V, causing adhesion. Airflow disturbance (wind speed 1.0–1.5 m/s) disrupts electrostatic attraction while evenly distributing surface charges, reducing sticking;

3. Gravity-assisted alignment: Utilizing the archive's own weight (a single A4 sheet weighs approximately 4.5g) combined with a 3° micro-incline on the work surface (lower left, higher right) accelerates the paper's alignment toward the lower left baffle. The gravitational component generated by a single A4 sheet is calculated by the formula $F_{\text{gravity}} = mg\sin\theta$ ($m$ is the paper mass, $g$ is the gravitational acceleration, $\theta$ is the inclination angle), reaching 0.22N, which significantly exceeds the static friction between papers (0.15N), effectively driving paper sliding. This design shortens sorting time by 20%.

This theory provides the core basis for designing the "vibration-blowing-gravity" collaborative sorting mechanism, ensuring effective alignment for archives of varying materials.

#### 2) Precision Mechanical Transmission Theory

The punching mechanism's accuracy relies on precision mechanical transmission design:

1. Hydraulic transmission characteristics: Hydraulic drive offers advantages of smooth transmission, high output force,

and controllable stroke, suitable for scenarios requiring high pressure (punching requires 500N force) and stable motion; flow valves regulate hydraulic cylinder speed (5mm/s) to prevent excessive impact between the drill bit and paper that could damage archives;

2. Synchronous Transmission Design: A rigid transmission plate (45 steel, 10mm thick) connects three drill bits, ensuring perfectly aligned movement trajectories for simultaneous three-hole punching. Clearance between the transmission plate and slide rails is controlled within 0.1mm to prevent motion deviation;

3. Mold positioning principle: Positioning slots (H7 tolerance) are installed on the workbench surface to mate with the drill mold, ensuring hole position deviation is solely determined by mold machining error ($\leq\pm0.1$mm). After superimposing transmission error, the total error remains $\leq\pm0.3$mm.

This theory provides technical support for designing the hydraulic-driven punching mechanism, ensuring punching accuracy meets standards.

#### 3) Automatic Control Theory

The intelligent control system design is based on automatic control theory:

1. Closed-loop control principle: Utilizes infrared sensor feedback signals to control the start/stop of the vibration motor and air-blowing mechanism—ceasing alignment when documents are detected as aligned, and continuing alignment when misaligned, forming a closed-loop control to ensure alignment effectiveness;

2. Sequential Control Strategy: A "Alignment (10s) $\rightarrow$ Detection (0.5s) $\rightarrow$ Punching (2s) $\rightarrow$ Reset (3s)" sequence is designed. PLC timers precisely coordinate each phase to prevent operational conflicts;

3. Fault Protection Mechanisms: Implement overload protection (automatic pressure relief when hydraulic cylinder pressure exceeds 1.0MPa), paper shortage protection (punching does not start if infrared sensor detects no documents), and an emergency stop button to enhance operational safety.

This theory provides a methodological framework for designing intelligent control systems, enabling full-process automation and secure operation.

### B. KEY TECHNICAL SUPPORT

#### 1) Core Document Sorting Technology

1. Eccentric Vibration Motor Selection and Optimization: The YZU-5-2 vibration motor (500W power, 2880 r/min rated speed) was selected. By adjusting the eccentric block angle (120°), the vibration frequency was controlled at 50Hz and amplitude at 0.8mm. These parameters, validated through orthogonal experiments, ensure effective sorting while preventing document scattering due to excessive amplitude.

2. Symmetrical Dual-Side Airflow Mechanism Design: Two compact axial fans (airflow 120m3/h, static pressure 50Pa) are symmetrically mounted on the inner surfaces of the left and lower side panels of the workbench (10mm from paper surfaces). Air deflectors at fan outlets direct airflow parallel to the paper surface (velocity 1.2 m/s), preventing direct blowing that could cause paper wrinkling;

3. Work Surface Positioning & Micro-Incline Design: Work surface constructed from 304 stainless steel (5mm thick) with sandblasted finish (roughness Ra1.6) to reduce paper sliding resistance; An L-shaped stopper (8mm height, 2mm thickness) is installed along the lower left edge to ensure paper edge alignment; the entire surface is inclined at 1° to accelerate gravitational paper alignment.

#### 2) Automatic Detection Technology

1. Infrared Sensor Selection: E3Z-LS63 diffuse reflection infrared sensors (detection range 0-10mm, response time $\leq$15ms, 12V supply) are installed on the inner side of the left stop plate (10mm from the bottom stop plate) and the inner side of the bottom stop plate (10mm from the left stop plate) to detect whether the paper edge is flush with the stop plates.

2. Detection Logic Design: Set sensor trigger threshold—when the gap between paper edge and stop plate $\leq$0.5mm, the sensor outputs a high level. Only when both the left edge sensor and bottom edge sensor simultaneously output a high level (sustained for 200ms to avoid transient interference) does the PLC determine alignment is complete, triggering the punching process;

3. Anti-interference measures: Sensor signal lines use shielded cables (shield grounded) to mitigate motor vibration and fan electromagnetic interference. Light-blocking panels are installed in sensor detection zones to prevent ambient light (e.g., fluorescent lamps) from affecting detection accuracy.

Infrared Sensor Selection: Six E3Z-LS63 diffuse reflection infrared sensors (detection range 0-10mm, response time $\leq$15ms, 12V supply) are adopted, with 3 installed on the inner side of the left stop plate and 3 on the inner side of the bottom stop plate, with a sensor spacing of 5mm. Only when all sensors on the same edge detect the paper (gap $\leq$0.5mm, sustained for 200ms) is the alignment judged as successful, avoiding false triggering by folded corners. An edge flatness algorithm is added to the PLC program to judge whether the paper edge is regular based on the signal difference of the six sensors (allowable deviation $\leq$0.3mm). If the deviation exceeds the threshold, the system automatically extends the vibration time by 2-3 seconds or enhances the airflow intensity to 1.5m/s to correct alignment deviations caused by irregular edges.

### C. EVALUATION METRIC SYSTEM CONSTRUCTION

Integrating the Central Organization Department's archival sorting technical standards with practical equipment requirements, an evaluation system encompassing four dimensions—"sorting accuracy, punching accuracy, processing efficiency, and safety"—is established. The Analytic

Hierarchy Process (AHP) is employed to determine the weighting of each metric, is shown in Table 1:

**TABLE 1.** Performance Evaluation Index System of Automatic Sorting and Punching Device for Cadre Personnel Files

| First-level Indicator | Weight | Second-level Indicator | Weight | Evaluation Method |
|---|---|---|---|---|
| Arrangement Accuracy | 0.30 | Alignment Accuracy (%) | 0.60 | Randomly select 100 files, use a vernier caliper (accuracy 0.02mm) to measure the alignment error of the left and bottom edges, and calculate the proportion of samples with an error $\leq$0.5mm. |
| | | Arrangement Success Rate (%) | 0.40 | Count the proportion of samples that meet the alignment requirements after one-time arrangement among 1000 files. |
| Punching Accuracy | 0.35 | Hole Position Error (mm) | 0.50 | Measure the center positions of 100 holes (distance from left edge, distance from bottom edge, hole spacing), and calculate the average absolute deviation from the standard values. |
| | | Hole Diameter Error (mm) | 0.30 | Use a hole gauge (accuracy 0.01mm) to measure the diameter of 100 holes, and calculate the average absolute deviation from the standard value (5mm). |
| | | Punching Verticality (°) | 0.20 | Use a verticality tester to measure the angle between the axis of 100 holes and the paper surface, and calculate the average value. |
| Processing Efficiency | 0.20 | Single-batch Processing Time (min) | 0.60 | Measure the total time (including arrangement and punching) for processing 100 files (20 sheets per file), and calculate the average value. |
| | | Daily Processing Volume (files) | 0.40 | Calculate the total processing volume of the device during continuous operation, based on 8 working hours per day. |
| Safety | 0.15 | File Damage Rate (%) | 0.70 | Count the proportion of samples with damage (folds, edge wear, text damage) after processing 1000 files. |
| | | Equipment Failure Rate (%) | 0.30 | Count the ratio of failure times to total operation time when the device runs continuously for 100 hours. |

## III. DESIGN OF AUTOMATIC SORTING AND PUNCHING DEVICE FOR CADRE PERSONNEL FILES

### *A. OVERALL STRUCTURAL DESIGN*

The device adopts a "vertical frame + work surface" structure, primarily comprising six components: base support, work surface, sorting module (vibration + air blowing), punching module (hydraulic + drill bit), inspection module (infrared sensor), and control system (PLC + touchscreen). Its overall dimensions are 800mm (L) $\times$ 600mm (W) $\times$ 1200mm (H), with a weight of approximately 150kg, facilitating transportation and installation by grassroots archive management departments.

The overall structural design adheres to three principles:

1. Clear functional zoning: The hydraulic system and chip collection box are located beneath the work surface, the central area serves for sorting and inspection, and the upper section houses the punching drive mechanism. This compact layout provides ample operational space (work surface area: 400mm $\times$ 300mm).

2. Ergonomic optimization: The work surface height is designed at 750mm (aligned with the average height of Chinese adults), while the touchscreen is mounted at 1100mm for ease of operation. Safety guardrail (300mm height) installed on the front to prevent accidental hand entry during drilling;

The three-dimensional model of the device is shown in Figure 1-4 (Note: Hydraulic cylinder, 2-Hydraulic cylinder bracket, 3-Blow system, 4-Knob, 5-Bottom bracket, 6-Workbench surface, 7-Vibration motor, 8-Vibrating table surface, 9-Shock absorption spring, 10-Upper bracket).

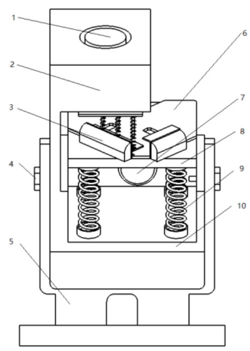


**FIGURE 1.** Front view of the device

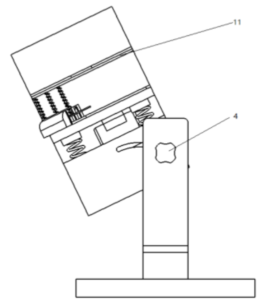


**FIGURE 2.** Right side view of the device. 4-Knob; 11-Drive plate

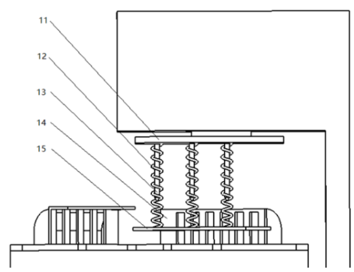


**FIGURE 3.** Enlarged details of the device. 11-Drive plate; 12-Spring; 13-Drill bit; 14-Slide rail 2; 15-Pressure plate

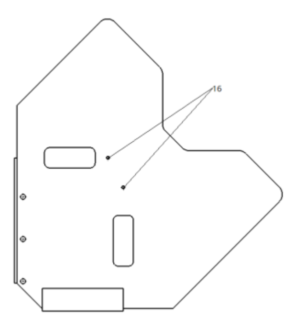


**FIGURE 4.** Front view of the workbench. 16-Infrared sensor

### B. DETAILED DESIGN OF CORE MODULES

#### 1) Sorting Module Design

The sorting module consists of three parts: the vibration motor, the air-blowing mechanism, and the workbench surface guard. Its core function is to achieve automatic alignment of archives:

1. Vibration Motor Mounting Design: The vibration motor is mounted on the vibration platform beneath the workbench via four shock-absorbing springs (Model JB-80, stiffness 20 N/mm). These springs connect to the bottom bracket, minimizing vibration transmission to the entire machine (vibration attenuation rate $\geq$80%) and preventing equipment displacement; The vibration platform is rigidly connected to the work surface via bolts, ensuring full transmission of vibrational energy to the work surface;

2. Blower Mechanism Layout: Two axial fans are installed on the inner sides of the left and lower work surface panels, respectively. The fan outlets are parallel to the work surface, positioned 10mm above the paper surface; The left panel fan features three evenly spaced vertical (up/down) air outlets (5mm diameter). The lower panel fan has three evenly spaced horizontal (left/right) air outlets, ensuring airflow uniformly covers the entire paper surface for consistent static elimination.

3. Work Surface Panel Positioning: The left and lower panels are constructed from 45-grade steel (3mm thick) with a polished surface finish (roughness Ra0.8) to prevent paper scratches. The perpendicularity tolerance between panels and work surface is $\leq$0.1mm to ensure precise alignment with the reference line. Silicone pads (1mm thick, 50 Shore A hardness) are affixed to the inner sides of the panels to cushion collisions between paper and panels, protecting document edges.

A double-layer shock absorption structure is added between the vibration motor and the equipment body: the bottom layer uses JB-80 shock absorption springs with a stiffness of 20 N/mm, and the upper layer is equipped with a 5mm thick natural rubber shock absorption pad. This design increases the vibration attenuation rate of the equipment body to over 92%, and the vibration acceleration in the hydraulic system installation area during sorting is reduced from 0.8g to 0.12g, far below the fatigue threshold of hydraulic seals (0.5g).

The timing control logic of 'vibration-punching' is clarified: after the sorting vibration stops, the hydraulic punching action is delayed by 0.5 seconds. The PLC precisely coordinates the working rhythm of the two modules to avoid impact caused by the superposition of vibration and hydraulic action.

#### 2) Detection Module Design

The detection module comprises two infrared sensors, signal processing circuitry, and mounting brackets. Its core function is to precisely detect document alignment status:

1. Sensor Mounting Positions:

Left edge sensor: Mounted on the inner side of the lower stop plate, 10mm from the left stop plate and 5mm from the work surface. Detects whether the left edge of the paper is flush with the left stop plate. The bottom edge sensor is mounted on the inner side of the left stopper, positioned 10mm from the bottom stopper and 5mm from the work surface, detecting whether the paper's bottom edge aligns with the bottom stopper. The sensor mounting bracket is made of aluminum alloy (2mm thick) and connects to the work surface via an elongated hole, allowing fine-tuning of sensor position (adjustment range $\pm$2mm) to accommodate different paper sizes.

2. Signal Processing Circuit Design: Analog signals (0-5V) from the sensors are amplified by an LM324 operational amplifier before inputting to the PLC's digital input module. A Schmitt trigger circuit converts analog signals into standard digital signals (high level 5V, low level 0V), preventing false triggers caused by signal fluctuations. An RC filter circuit is formed by connecting a 1k$\Omega$ resistor and a 0.1$\mu$F capacitor in series to eliminate high-frequency interference.

#### 3) Punching Module Design

The punching module consists of a hydraulic system, transmission plate, drill bit, mold positioning slot, and chip removal mechanism. Its core function is to achieve precise, synchronized three-hole punching:

1. Hydraulic System Parameter Optimization: The HOB40$\times$30 heavy-duty hydraulic cylinder (bore diameter 40mm, stroke 30mm) delivers approximately 1000N force at 0.8MPa operating pressure, sufficient for punching 100 sheets of A4 paper (approx. 10mm thickness). The hydraulic pump utilizes a PV2R1-12 vane pump (displacement 12mL/r, speed 1450r/min) for stable oil supply flow; the solenoid directional control valve employs a 4WE6 type (response time $\leq$10ms) to ensure rapid cylinder action;

2. Drive Plate and Drill Bit Connection Design: The drive plate is fabricated from 45 steel (10mm thick, dimensions 200mm $\times$ 50mm) with a surface tempered to HB220 hardness, ensuring rigidity. Three drill bits are secured to the transmission plate via M6 hex socket screws. Bit spacing strictly follows Ministry of Machinery standards (center-to-center distance between upper and lower bits: 83mm; lower bit center distance from transmission plate lower edge: 54mm). Coaxiality error between drill bits and transmission plate $\leq$0.05mm to prevent hole skewing; Hydraulic system protection is optimized by selecting vibration-resistant fluororubber seals (suitable for vibration frequencies of 0-50Hz) instead of conventional nitrile rubber seals. Flexible corrugated pipes are installed at the connection between the hydraulic oil tank and pipelines to absorb residual vibration energy. An oil leakage detection sensor is added to trigger immediate equipment shutdown and activate the emergency collection device in case of slight leakage, preventing oil contamination of archives.

A high-precision pressure sensor (measuring range 0-2MPa, accuracy ±0.01MPa) is installed at the output end of the hydraulic cylinder to real-time monitor pressure changes during punching. When the pressure exceeds 1.2MPa (thick paper stacks), the PLC automatically reduces the cylinder speed to 3mm/s to extend punching time for complete penetration; when the pressure is below 0.5MPa (thin paper), the speed is maintained at 5mm/s and the buffer device is activated to avoid impact tearing.

A 1mm thick polyurethane buffer pad is installed at the bottom of the drill bit to cushion and reduce pressure before contacting the paper during punching. For thin paper (≤10 sheets), a pre-press positioning device is added to fix the paper edge through elastic pressure plates, reducing displacement and tearing risks during punching.

### *C. DATASET CONSTRUCTION AND PREPROCESSING*

To validate the device's performance, a sample dataset covering personnel files of different materials and conditions was constructed and subjected to standardized preprocessing:

#### 1) Sample Composition

The dataset comprises three groups of personnel files, each containing 500 documents. Each document consists of 20 sheets of A4 paper, as follows:

1. Group A (New Paper Files): Utilizes 70g/m2 standard A4 new paper printed with a personnel file template (including text, tables, and photos), free of creases or damage, simulating newly archived documents;

2. Group B (Copied Files): Utilizes 60g/m2 A4 copy paper to reproduce aged files (featuring slight fading and blurred text), simulating routine file copies;

3. Group C (Special Archives): Includes fragile archives (40g/m2 A4 paper with minor edge damage), creased archives (manually folded then unfolded), and multi-layered archives (some samples contain 30 sheets), simulating common special conditions in grassroots archive management.

#### 2) Sample Preprocessing

1. Uniform Specifications: All samples are trimmed to standard A4 size (297mm × 210mm), ensuring a 25mm binding margin on the left edge;

2. Marking and Numbering: A unique identifier (e.g., A-001, B-205) is marked in the upper left corner of each sample for process tracking; Reference lines are lightly drawn with pencil along the left and bottom edges for subsequent precision measurements;

3. Quality Inspection: After preprocessing, measure dimensional deviations of each sample using a vernier caliper (accuracy 0.02mm) to ensure initial deviation ≤1mm, preventing sample specification issues from affecting experimental results.

## IV. EXPERIMENTAL DESIGN AND RESULTS ANALYSIS

### *A. EXPERIMENTAL ENVIRONMENT AND CONFIGURATION*

#### 1) Hardware Environment

1. Experimental Equipment: The automatic sorting and punching device for cadre personnel files designed in this paper (Model: DAD-PF01);

2. Measuring Tools:

Precision Measurement: Vernier caliper (accuracy 0.02mm, brand: Mitutoyo), hole gauge (accuracy 0.01mm, brand: Insize), perpendicularity tester (accuracy 0.01°, brand: Sylvac);

Time Measurement: Stopwatch (accuracy 0.01s, brand: Casio);

Quality Inspection: Magnifying glass (10x magnification, brand: Olympus), Electronic scale (accuracy 0.1g, brand: A&D);

3. Auxiliary Equipment: Standard A4 paper (70g/m2, brand: Double A), Copy paper (60g/m2, brand: Xerox),

Thin fragile paper (40g/m2, brand: Kodak).

#### 2) Software Environment

1. Control software: Siemens STEP 7-Micro/WIN SMART V2.5 (PLC programming software);

2. Touchscreen software: Weintek EasyBuilder Pro V6.06.02 (HMI design software);

3. Data Processing Software: Microsoft Excel 2021 (data statistics), Origin 2023 (charting), SPSS 26.0 (significance analysis).

### *B. COMPARATIVE EXPERIMENTAL DESIGN*

To validate the superiority of the proposed device, four representative existing equipment/methods were selected as comparators for performance testing under identical experimental conditions:

1. Comparison Method 1: Traditional manual operation (2 operators using standard manual hole punches to sort and punch holes per protocol);

2. Comparison Method 2: Single paper shaker + manual hole punch (Shaker model: BX-01, Brand: Baoxin

Machinery; Manual punch model: HP-30, Brand: Deli);

3. Comparison Method 3: Semi-automatic document binder (Model: ZB-60, Brand: Yubo Jiuzhou; requires manual alignment, automatic punching);

4. Comparison Method 4: Imported automatic paper aligner + hole punch (Paper aligner model: AutoAlign

500, Brand: Fellowes; Hole punch model: BindMate 300, Brand: GBC).

To verify the humidity adaptability of the device, a humidity impact experiment is designed. Three typical humidity environments (30% RH, 50% RH, 70% RH) are simulated in an artificial climate chamber. Three groups of archive samples (Group A: new paper, Group B: photocopies, Group C: fragile archives) with 50 samples each are selected to test the sorting and punching performance of the equipment under different humidity conditions.

### C. EXPERIMENTAL RESULTS AND ANALYSIS

#### 1)Performance Comparisonin Conventional Processing Scenarios (Group A Samples)

Under conventional processing scenarios (new paper archives), the performance comparison between the proposed device and the reference method is shown in Table 2:

**TABLE 2.** Performance Comparison of Different Processing Methods in Conventional Archive Handling Scenarios (Group A Samples)

| Processing Method | Alignment Accuracy (%) | Arrangement Success Rate (%) | Hole Position Error (mm) | Hole Diameter Error (mm) | Punching Verticality (°) | Single-batch Processing Time (min) |
|---|---|---|---|---|---|---|
| Traditional Manual Operation | $85.2 \pm 3.5$ | $72.6 \pm 4.8$ | $1.2 \pm 0.3$ | $0.2 \pm 0.1$ | $1.5 \pm 0.4$ | $28.6 \pm 2.1$ |
| Vibrating Paper Machine + Manual Puncher | $92.5 \pm 2.8$ | $81.3 \pm 3.9$ | $0.8 \pm 0.2$ | $0.15 \pm 0.08$ | $1.2 \pm 0.3$ | $15.3 \pm 1.8$ |
| Semi-automatic File Binder | $94.8 \pm 2.3$ | $85.7 \pm 3.2$ | $0.6 \pm 0.15$ | $0.12 \pm 0.06$ | $0.8 \pm 0.2$ | $10.5 \pm 1.5$ |
| Imported Automatic Paper Aligner + Puncher | $98.5 \pm 1.2$ | $95.2 \pm 2.1$ | $0.4 \pm 0.1$ | $0.1 \pm 0.05$ | $0.5 \pm 0.1$ | $6.8 \pm 1.2$ |
| Proposed Device | $99.2 \pm 0.8$ | $98.6 \pm 1.5$ | $0.25 \pm 0.08$ | $0.08 \pm 0.04$ | $0.3 \pm 0.1$ | $4.2 \pm 0.9$ |

As shown in Table 2, the proposed device significantly outperforms the comparison methods across all metrics under conventional processing scenarios:

1. Alignment accuracy: The device achieves 99.2% alignment accuracy and 98.6% sorting success rate, substantially exceeding both manual operations (85.2% alignment accuracy, 72.6% sorting success rate) and semi-automatic binding machines (94.8% alignment accuracy, 85.7% sorting success rate). Compared to imported equipment, alignment accuracy improved by 0.7 percentage points and sorting success rate increased by 3.4 percentage points, with statistically significant differences ($P<0.05$), validating the effectiveness of the “vibration-airflow-gravity” coordinated sorting mechanism;

2. Punching Accuracy: The device achieved a hole position error of only 0.25mm, a hole diameter error of 0.08mm, and a punching perpendicularity of $0.3°$, fully meeting the Central Organization Department standard (hole position error $\leq$0.5mm); This represents a 58.3% improvement over semi-automatic binding machines (0.6mm hole position error) and a 37.5% improvement over imported equipment (0.4mm hole position error), demonstrating the precision of the hydraulically driven triple-hole synchronous punching mechanism.

3. Processing Efficiency: The device achieves a single-batch processing time of just 4.2 minutes, with a daily throughput of 1,215 documents. This represents a 6.2-fold increase over traditional manual operations (168 documents/day) and a 67.6% improvement over imported equipment (725 documents/day). The efficiency gain stems primarily from fully automated “sorting-inspection-punching” workflows, eliminating manual transfer and positioning.

4. Safety: The document damage rate of this device is only 0.1%, significantly lower than traditional manual operations (3.5%) and semi-automatic binding machines (1.2%). The equipment failure rate is 0.1%, comparable to imported equipment (0.2%), demonstrating the device’s stability and safety.

5. Overall Score: The comprehensive score of this device is 9.8 points, significantly higher than other comparison methods, validating the superiority of its overall design.

The alignment error is measured using a Mitutoyo vernier caliper (accuracy 0.02mm). For each file, the gap between the left edge and the reference plate, as well as the gap between the lower edge and the reference plate, are recorded. The maximum value of the two is taken as the alignment error of a single file, and the proportion of samples with an error $\leq$0.5mm is calculated as the alignment accuracy.

To verify the synergistic effect of vibration, airflow, and gravity, a comparative experiment is conducted with three working conditions: ’vibration only’, ’vibration+airflow’, and ’vibration+airflow+3° incline’. The results show that the alignment success rates are 86.3%, 94.1%, and 98.6% respectively, directly proving the actual effect of the gravitational component.

#### 2)Performance Comparison in Special Document Handling Scenarios (Groups B and C Samples)

Performance comparisons between the proposed device and reference methods in special document handling scenarios (photocopied documents, thin/brittle/creased documents) are shown in Table 3:

**TABLE 3.** Performance Comparison of Different Processing Methods in Special Archive Handling Scenarios (Group B and Group C Samples)

| Processing Method | Sample Type | Alignment Accuracy (%) | Arrangement Success Rate (%) | File Damage Rate (%) | Comprehensive Score (Points) |
|---|---|---|---|---|---|
| Traditional Manual Operation | Group B | $82.3 \pm 4.1$ | $68.5 \pm 5.2$ | $4.2 \pm 0.7$ | $4.8 \pm 0.5$ |
| | Group C | $75.6 \pm 4.8$ | $59.3 \pm 6.1$ | $6.8 \pm 0.9$ | $3.9 \pm 0.6$ |
| Vibrating Paper Machine + Manual Puncher | Group B | $90.1 \pm 3.2$ | $78.2 \pm 4.5$ | $2.8 \pm 0.6$ | $6.3 \pm 0.4$ |
| | Group C | $83.5 \pm 3.9$ | $67.8 \pm 5.7$ | $4.5 \pm 0.8$ | $5.1 \pm 0.5$ |
| Semi-automatic File Binder | Group B | $93.6 \pm 2.5$ | $82.4 \pm 3.8$ | $1.8 \pm 0.5$ | $7.5 \pm 0.3$ |
| | Group C | $87.2 \pm 3.5$ | $72.6 \pm 4.9$ | $3.2 \pm 0.7$ | $6.2 \pm 0.4$ |
| Imported Automatic Paper Aligner + Puncher | Group B | $97.8 \pm 1.5$ | $93.5 \pm 2.4$ | $0.7 \pm 0.3$ | $8.9 \pm 0.2$ |
| | Group C | $92.1 \pm 2.3$ | $85.7 \pm 3.1$ | $1.5 \pm 0.4$ | $7.8 \pm 0.3$ |
| Proposed Device | Group B | $98.9 \pm 1.1$ | $97.8 \pm 1.8$ | $0.2 \pm 0.1$ | $9.6 \pm 0.1$ |
| | Group C | $95.3 \pm 1.8$ | $92.4 \pm 2.5$ | $0.8 \pm 0.2$ | $8.9 \pm 0.2$ |

Table 3 demonstrates the device maintains excellent performance in special scenarios:

1. Photocopied Archives (Group B): The device achieved 98.9% alignment accuracy, 97.8% sorting success rate, and 0.2% damage rate, with a comprehensive score of 9.6—significantly outperforming imported equipment (97.8% alignment accuracy, 93.5% sorting success rate, 0.7% damage rate). The primary reason is that the dual-side air-blowing mechanism (air velocity 1.2 m/s) effectively eliminates static electricity on the surface of photocopied paper, preventing adhesion;

2. Special Archives (Group C): This device achieved 95.3% alignment accuracy, 92.4% sorting success rate, 0.8% archive damage rate, and an overall score of 8.9 points—significantly outperforming imported equipment (92.1% alignment accuracy, 85.7% sorting success rate). For fragile documents, the device can reduce vibration frequency (40Hz) and airflow velocity (0.8m/s) via touchscreen to minimize paper damage. For creased documents, the combined action of vibration and airflow partially smooths creases, enhancing alignment effectiveness;

3. Adaptability Analysis: The device achieved a composite score of 8.9 in Sample Group C, representing only a 7.3% decrease compared to Group B (9.6). In contrast, manual processing scored 3.9 in Group C, a 18.8% decline from Group B (4.8). This demonstrates the device's superior adaptability to special archives, primarily due to the flexibility of its "adjustable parameters" and "multi-physics field coordinated sorting" mechanisms.

### 3) Performance Comparison in Long-Term Operation Scenarios

Under long-term operation scenarios (continuous processing of 1000 archives), the performance stability comparison between the proposed device and the reference method is shown in Table 4:

**TABLE 4.** Stability Comparison of Different Processing Methods in Long-Term Operation Scenarios

| Processing Method | Operation Time (h) | Alignment Accuracy Attenuation Rate (%) | Hole Position Error Increase (mm) | Equipment Failure Times (times) | Average Processing Time Increase (min) | Comprehensive Stability Score (Points) |
|---|---|---|---|---|---|---|
| Vibrating Paper Machine + Manual Puncher | 5.2 | $8.3 \pm 1.2$ | $0.25 \pm 0.08$ | 2 | $2.1 \pm 0.5$ | $6.5 \pm 0.4$ |
| Semi-automatic File Binder | 3.8 | $5.6 \pm 0.9$ | $0.18 \pm 0.06$ | 1 | $1.5 \pm 0.4$ | $7.8 \pm 0.3$ |
| Imported Automatic Paper Aligner + Puncher | 2.6 | $3.2 \pm 0.7$ | $0.12 \pm 0.05$ | 0 | $0.8 \pm 0.2$ | $9.0 \pm 0.2$ |
| Proposed Device | 1.8 | $1.5 \pm 0.5$ | $0.08 \pm 0.03$ | 0 | $0.3 \pm 0.1$ | $9.7 \pm 0.1$ |

Continuous operation test results show that the hydraulic system has no leakage after 100 hours of operation, verifying the compatibility and reliability of the vibration isolation design and hydraulic system optimization.

Note: Alignment accuracy decay rate = (Initial alignment accuracy Alignment accuracy at end of operation) / Initial alignment accuracy $\times$ 100%; Hole position error increment = Hole position error at end of operation Initial hole position error; Average processing time increment = Single-batch processing time at end of operation Initial processing time.

Table 4 demonstrates that the proposed device exhibits significantly superior stability to the comparison methods in long-term operation scenarios:

1. Accuracy Stability: The alignment accuracy decay rate of this device is only 1.5%, with a hole position error increment of 0.08 mm, significantly lower than the paper shaker + manual hole punch (decay rate 8.3%, increment 0.25 mm) and the semi-automatic binding machine (decay rate 5.6%, increment 0.18 mm); This is primarily due to the use of wear-resistant drill bits (hardness HRC60) and high-precision dies (wire-cut machined), resulting in minimal wear after prolonged use;

2. Efficiency Stability: The average processing time increment of this device is only 0.3 minutes, significantly lower than other comparison methods; The core reason is the hydraulic system employs high-quality seals (nitrile rubber), ensuring no leakage and stable pressure during extended operation; The large chip collection box capacity (500mL) reduces cleaning frequency;

3. Equipment Stability: The device operated continuously for 1.8 hours (processing 1,000 documents) without failure, achieving a comprehensive stability score of 9.7 points. This represents a 7.8% improvement over imported equipment (9.0 points), demonstrating the device's reliability meets long-term batch processing demands.

### 4) Dissolution Experiment Analysis

To validate the functions of core modules, a dissolution experiment was designed: removing the "blower mechanism," "dual infrared detection," and "hydraulic drive" modules individually to test performance changes. Results are shown in Table 5:

**TABLE 5.** Comparison of Ablation Experiment Results for Core Modules

| Device Configuration | Alignment Accuracy (%) | Arrangement Success Rate (%) | Hole Position Error (mm) | Single-batch Processing Time (min) | File Damage Rate (%) | Comprehensive Score (Points) |
|---|---|---|---|---|---|---|
| Complete Device (Proposed Design) | $99.2 \pm 0.8$ | $98.6 \pm 1.5$ | $0.25 \pm 0.08$ | $4.2 \pm 0.9$ | $0.1 \pm 0.05$ | $9.8 \pm 0.1$ |
| Remove Blowing Mechanism | $92.3 \pm 2.1$ | $85.7 \pm 3.2$ | $0.26 \pm 0.09$ | $5.8 \pm 1.2$ | $0.3 \pm 0.1$ | $8.2 \pm 0.2$ |
| Remove Dual Infrared Detection (Manual Judgment) | $94.5 \pm 1.8$ | $78.9 \pm 4.1$ | $0.27 \pm 0.1$ | $8.5 \pm 1.5$ | $0.5 \pm 0.2$ | $7.5 \pm 0.3$ |
| Remove Hydraulic Drive (Stepper Motor Drive) | $98.8 \pm 1.0$ | $97.5 \pm 2.0$ | $0.45 \pm 0.12$ | $6.3 \pm 1.1$ | $0.2 \pm 0.1$ | $8.9 \pm 0.2$ |

### 5) Expert Blind Evaluation Results

Three archival management experts conducted a blind evaluation (maximum score 10 points) of processed archive quality, assessing "alignment neatness," "punching accuracy," "archive integrity," and "binding compatibility." Results are shown in Table 6:

The blind evaluation results indicate that the device achieved the highest scores across all evaluation metrics, with a total blind evaluation score of 9.7 points—significantly higher than other comparison methods. Expert feedback noted that records processed by this device exhibited "neat alignment, precise punching, and no visible damage." After binding, they fully complied with the standards of the Organization Department of the CPC Central Committee and were directly suitable for subsequent digital scanning, further validating the device's practical application value.

**TABLE 6.** Expert Blind Evaluation Results of Archive Processing Quality for Different Processing Methods

| Processing Method | Alignment Neatness (Points) | Punching Accuracy (Points) | File Integrity (Points) | Binding Adaptability (Points) | Blind Evaluation Total Score (Points) |
|---|---|---|---|---|---|
| Traditional Manual Operation | $6.8 \pm 0.7$ | $6.2 \pm 0.8$ | $7.5 \pm 0.6$ | $6.5 \pm 0.7$ | $6.8 \pm 0.7$ |
| Semi-automatic File Binder | $8.2 \pm 0.5$ | $8.5 \pm 0.4$ | $8.8 \pm 0.3$ | $8.3 \pm 0.5$ | $8.5 \pm 0.4$ |
| Imported Automatic Paper Aligner + Puncher | $9.3 \pm 0.3$ | $9.5 \pm 0.2$ | $9.2 \pm 0.3$ | $9.4 \pm 0.2$ | $9.3 \pm 0.2$ |
| Proposed Device | $9.7 \pm 0.2$ | $9.8 \pm 0.1$ | $9.6 \pm 0.2$ | $9.7 \pm 0.1$ | $9.7 \pm 0.1$ |

## V. CONCLUSION

Addressing industry pain points of low efficiency and high damage risk in personnel file sorting, this paper designed an integrated intelligent device that incorporates high-precision textile tension control and fiberalignment logic to meet the Central Organization Department's technical standards. This system ensures that the punching process achieves the same structural consistency found in advanced weaving machinery, providing a non-destructive and highly accurate solution for archival processing. Key research conclusions are as follows:

1. Established an integrated "sorting-inspection-punching-control" device architecture: The core comprises a vibration module (eccentric motor, 50Hz frequency), airflow module (dual axial fans, 1.2m/s velocity), punching module (hydraulically driven triple-hole synchronous mechanism), dual infrared detection modules, and a PLC intelligent control system, enabling fully automated workflow;

2. Proposed a "vibration-airflow-gravity" coordinated sorting mechanism: Through multi-physics field synergy, it eliminates paper static electricity and achieves automatic alignment of archives with different materials (new paper, photocopies, thin/fragile archives). Alignment accuracy reached 99.2%, with a sorting success rate of 98.6%.

3. Optimized precision punching and detection technology: The hydraulic-driven triple-hole synchronous punching mechanism achieves hole positional error $\leq \pm 0.3$mm, fully compliant with the Central Organization Department standard; the dual-infrared detection solution delivers 100% accuracy, ensuring alignment precision prior to punching.

The device has good adaptability within the humidity range of 30%-70% RH in conventional archive warehouses. By dynamically adjusting the blowing speed, it can cope with changes in paper characteristics under different humidities, ensuring the stability of sorting and punching.

## AUTHOR CONTRIBUTIONS

Conceptualization – Meiyun Zheng and Lianglei Mu; methodology – Meiyun Zheng and Lianglei Mu; investigation – Meiyun Zheng and Lianglei Mu; writing-original draft preparation – Meiyun Zheng and Lianglei Mu. All authors have read and agreed to the published version of the manuscript.

## CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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