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Original Research Article

Design of a precision concrete spreader for prefabricated components based on PLC intelligent control

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Abstract: Prefabricated construction, an innovative approach with energy efficiency, low carbon emissions, lightweight design, and material recyclability, has strong national policy support in China. Precast concrete elements (PCEs) are the most critical component in prefabricated buildings, and the intelligence and automation of concrete spreader equipment determine manufacturing efficiency and product quality. Currently, most spreaders rely on manual or semi - mechanized operations, causing uneven material distribution, high spoilage rates, limited coverage, and high equipment failure rates. By 2024, automated spreaders accounted for 63% of the market share, showing an industrial transition driven by advanced numerical control (NC) systems and robotics. To solve these problems, this study develops a fully intelligent precision concrete spreader for prefabricated components using a Siemens S7 - 200 SMART programmable logic controller (PLC) and SolidWorks 3D modeling. The system integrates a 12 - channel independent hydraulic discharge mechanism, a dual - track traversal structure, a three - level anti - collision protection system, and a PID closed - loop material control algorithm with load cell feedback. The design supports modular manufacturing, easy maintenance, and scalable automation upgrades including machine vision integration for future use.
Keywords: precast concrete components; prefabricated construction; programmable logic controller; concrete spreader; PID control; SolidWorks

1. Introduction

1.1. Research background and significance

Prefabricated construction has undergone rapid expansion in China under favorable national policy conditions. Policy mandates across most provinces require prefabricated building ratios to exceed 30% of new construction area by 2025, with select regions such as Tianjin and Shanghai enforcing 100% adoption (Wang & Liu, 2017).

Precast concrete elements (PCEs), as the core components of prefabricated buildings, have their production efficiency and quality directly constrained by the performance of concrete spreader equipment. Traditional spreaders predominantly rely on manual discharge control with low automation levels, resulting in poor material uniformity, concrete adhesion and solidification on hopper walls, significant raw material waste, and limited traversal coverage areas. The high collision failure rate of traversal mechanisms also impedes standardized production line operation. Although extensive research has been conducted on spreader equipment domestically (Yu & Jiang, 2004; Zhang & Yan, 2015), the literature indicates a persistent gap in integrated electromechanical design combining PLC-based electrical control, anti-adhesion structures, dual-track traversal, and multi-level anti-collision protection.

The present study develops an intelligent, fully mechanized precision spreader through mechatronics integration, PLC automatic control, and finite element simulation optimization. This approach achieves complete intelligent management of the concrete distribution process and delivers significant practical value in improving component forming accuracy, reducing concrete raw material consumption, decreasing on-site labor requirements, and lowering equipment failure rates—Aligning with the construction industry's drive toward energy conservation, emission reduction, and green industrialization.

1.2. Literature review

Domestic and international research on prefabricated concrete spreader equipment shows a technological

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gap. China started late in development. Most spreaders rely on on - off hydraulic valves and discrete electrical controls, causing high failure rates and significant boom vibration. Structural design is experience - based, lacking systematic finite - element mechanical verification for key components like main beams and hoppers, leading to excessive design redundancy and high machine weight. Manufacturing processes are crude, with insufficient standardization in pipeline routing and weld treatment, limited prototype testing, and lack of specialized experiments on anti - blockage and precision material control, which hinders large - scale production of high - precision precast components. In contrast, leading European and American manufacturers use electro - hydraulic proportional control combined with PLC technology, which is reliable, easy to control, energy - efficient, cost - effective, high - precision, and smooth in operation. For example, Shanghai Institute of Technology implemented PLC - centric control systems for hydraulic manipulator retrofitting, meeting all requirements. These integrated electrical control solutions, supported by NC machining and automated welding, ensure good reliability and dynamic performance. However, the high cost of imported equipment challenges small and medium - sized precast component plants in China.

1.3. Scope of this study

The principal research contvents of this work are as follows:

(1) 3D modeling of the complete spreader: Modular mechanical structure design is performed, and a three-dimensional solid model of the spreader is constructed using SolidWorks software (Yang, 2024; Yang, 2022), completing the structural design and material selection for the traversal mechanism, material storage system, and anti-collision mechanism.

(2) PLC control system design: The complete machine uses a Siemens S7-200 SMART PLC as the master control unit, forming a control system together with a touchscreen, wireless remote controller, multi-channel hydraulic solenoid valves, and variable-frequency drives. A dual-control mode combining local panel and wireless remote operation provides flexible and convenient operation.

2. Three-dimensional machine modeling

The spreader is composed of five major assemblies: The material storage hopper assembly, the anti-collision limit mechanism, the traversal mechanism, and the PLC electrical control assembly. The structural details of each module are described below.

2.1. Material storage hopper assembly

The material storage hopper assembly (**Figure 1**) comprises a platform, a discharge guide port, and a discharge hopper. The platform serves primarily as a protective cover to prevent scattered material from damaging the hydraulic system and other components below. The discharge guide port ensures smooth entry of concrete material into the hopper while filtering out large aggregate particles. The discharge hopper is used for storing and mixing concrete material.

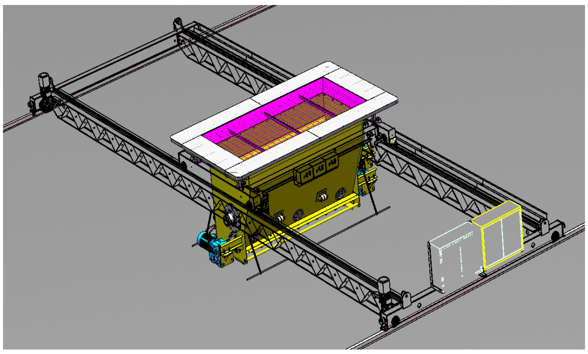

Figure 1. Three-dimensional model.

Figure 2. Mixing shaft.

A mixing shaft is installed inside the hopper (**Figure 2**). It provides continuous agitation to prevent concrete layering and segregation caused by gravity and friction, guaranteeing material uniformity and quality stability. Also, it breaks up and disperses aggregate accumulations, preventing discharge - port blockage, ensuring smooth and efficient distribution, minimizing raw material waste, and reducing equipment shutdown failure probability.

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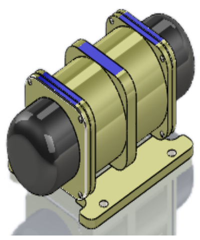

Figure 3. Vibrator.

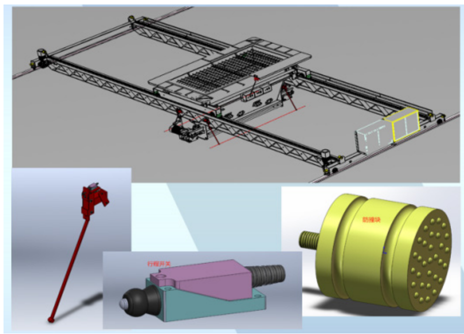

Figure 4. Anti-collision limit mechanism.

One vibrator is installed at each end of the hopper (**Figure 3**), effectively ensuring smooth material discharge. The vibrators exploit high-frequency vibration not only to prevent air bubble entrapment but also to reduce material adhesion and residue on the hopper walls, thereby improving concrete utilization efficiency.

2.2. Anti-collision limit mechanism

The anti - collision limit mechanism (**Figure 4**) mainly consists of collision blocks and limit switches. Collision blocks are installed at the four terminal ends of the gantry trolley and material cart to prevent collisions. Anti - collision rods and limit switches are mounted on the hopper. They prevent interference collisions when the hopper moves in the trolley track and trigger travel switches at designated positions, enabling automatic stop - on - arrival.

2.3. PLC control system overview

The complete machine uses a programmable logic controller (PLC) as the master control unit, supplemented by auxiliary microcontrollers, multi-channel hydraulic valve banks, and variable-frequency drive motors, operated through a dual-control mode combining local panel and wireless remote operation. Upon receiving control signals, the PLC independently controls the start/stop of 12 groups of hydraulic discharge cylinders, enabling individual opening and closing of each discharge port. Simultaneously, it controls the variable-frequency motor speed of both the gantry trolley and the material cart.

3. PLC intelligent control system design

3.1. Control system hardware selection

The control system uses the Siemens S7-200 SMART SR40 PLC as the master control unit. The core hardware components are listed in **Table 1**.

Table 1. Core hardware selection for the control system.

Equipment	Model / Specification	Qty	Function
Programmable Logic Controller	Siemens S7-200 SMART SR40	1 unit	System logic control and data processing
Touchscreen HMI	Weintek MT8071IP	1 unit	Parameter setting and status monitoring
Wireless Remote Controller	Yuding F24-12S	1 set	Remote wireless operation
Electromagnetic Directional Valve	4WE6D61B/CG24N9Z5L	12 units	Control discharge hydraulic cylinder open/close
Variable-Frequency Drive	Mitsubishi FR-D740-1.5K-CHT	3 units	Speed regulation for gantry, cart, and mixing motors
Load Cell	AVIC Measurement YZC-5B/5t	4 units	Real-time hopper weight monitoring
Travel Switch	Omron WLCA12-2	8 units	Limit position protection
Infrared Photoelectric Sensor	Omron E3F-DS10C4	4 units	Obstacle early warning detection

3.2. Control system software design

The control system software is developed using STEP 7-Micro/WIN SMART, employing a modular programming methodology. The software architecture comprises the main program and the following functional modules: Initialization module, traversal control module, discharge control module, anti-collision protection module, PID regulation module, and fault diagnosis module.

The main program cyclically invokes all functional modules to ensure continuous system operation. The initialization module performs power-on self-testing, parameter initialization, and device reset. The traversal control module implements manual/automatic operation and variable-frequency speed regulation for the gantry trolley and material cart. The discharge control module enables independent opening/closing and aperture adjustment for all 12 discharge ports. The anti-collision protection module provides obstacle pre-warning, limit-position shutdown, and emergency stop functions. The PID regulation module dynamically corrects discharge speed and traversal speed based on real-time feedback from load cells, ensuring precise quantitative material distribution (Zou et al., 2020). The fault diagnosis module monitors system operating status in real time, automatically halting operation and displaying fault location codes and remediation procedures on the touchscreen upon fault detection.

3.3. Core function implementation

3.3.1. 12-Channel independent discharge control

Each discharge port corresponds to an independent control circuit. Opening/closing time and aperture can be individually configured via the touchscreen. The system supports both manual single-point control and automatic zone-based distribution, satisfying the concrete placement requirements for precast components of diverse geometries (Liu, 2021; Ding, 2019).

3.3.2. Dual-track traversal variable-frequency speed regulation

The gantry trolley and material cart drive motors utilize variable-frequency drives, conforming to variable-frequency motor speed regulation technical standards. The drive speed regulation range is 0–30 m/min, allowing real-time adjustment of traversal speed according to prefabricated component thickness and concrete slump. Repeated positioning accuracy is ±5 mm. The motor pole configuration ensures stable torque output throughout the full speed regulation range, guaranteeing precise control at low speeds and further enhancing equipment operational reliability.

3.3.3. Three-level anti-collision automatic stop

When infrared photoelectric sensors detect an obstacle within a 1 m range, the system automatically decelerates and activates audible and visual alarms. Upon contact with a travel switch, the traversal motor power supply is immediately disconnected. Rubber collision blocks serve as the final physical buffer. This three-layer protection mechanism ensures operational safety, with an emergency stop response time of ≤0.5 s (Zhang et al., 2018).

4. Conclusions

This study designed an intelligent precision concrete spreader for prefabricated components based on PLC intelligent control to address traditional prefabricated component spreaders' deficiencies, such as low efficiency, poor precision, material waste, and inadequate safety.

The proposed design has a rational structure, mature manufacturing processes, and stable performance, and is applicable to prefabricated component production lines, providing technical support for intelligent upgrading of prefabricated construction equipment. Future research may optimize control system algorithms and integrate machine vision technology for automatic mold recognition and distribution path planning to advance equipment automation (Yang, 2024).

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