

Analysis of the Application of UW500 Series Distributed Control System in Pesticide Formulation Automation Production Management

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Abstract: The pesticide formulation production process requires high precision in control, complex processes, and strict safety and environmental protection standards, making it essential to adopt advanced automation control systems to improve production management. This paper addresses the automation upgrade needs of a pesticide formulation production line, utilizing the UW500 series distributed control system for transformation. By analyzing the system's functional features, a comprehensive process control plan was designed, achieving automation from raw material weighing to finished product packaging. The system's application results indicate significant improvements in key indicators such as product quality, production efficiency, and safety and environmental protection, leading to substantial economic benefits. Practice has shown that the UW500 series distributed control system can effectively meet the automation control needs of pesticide formulation production, providing practical reference for industry intelligent manufacturing upgrades.

Keywords: Pesticide formulation; distributed control system; automation control; process optimization; safety and environmental protection.

1. Introduction

The complexity and high precision requirements of pesticide formulation production processes present severe challenges for automation control systems[1]. The production process involves multiple steps such as material weighing, emulsification, blending, and filling, with each step's process parameters interrelated and strictly regulated. Traditional manual operations and single control modes are insufficient to ensure product quality stability. Especially in the context of increasingly stringent safety and environmental protection requirements, companies need to enhance intrinsic safety levels through advanced control systems[2]. The UW500 series distributed control system, with its comprehensive process control functions and reliable system architecture, has been widely applied in industrial process automation. This paper takes a pesticide formulation production line as an example to analyze the application effects of the UW500 series system in process control, quality management, and safety and environmental protection[3]. The paper discusses its implementation plan and application value in the automation upgrade of pesticide formulation production.

2. Overview of UW500 Series DCS System

2.1. Overview of UW500 Series DCS System

The UW500 series Distributed Control System (DCS) adopts a layered distributed architecture, consisting of three levels: the field control layer, the process monitoring layer, and the management layer. The system utilizes dual-machine hot standby redundancy technology to ensure high reliability and continuity of the control system[4]. It is equipped with

high-performance industrial-grade controllers, providing powerful real-time data processing capabilities and network communication functions. The system supports multi-task parallel processing and can handle multiple complex control processes simultaneously. The system is also equipped with large-capacity industrial-grade data servers, capable of collecting, storing, and managing massive process data, providing data support for production process optimization and decision-making analysis.

2.2. System Features and Application Advantages

The UW500 series DCS system fully reflects the characteristics and needs of pesticide formulation production in its functional design. Data analysis from system operation indicates that the system performs excellently in process control precision. As shown in Table 1, in terms of temperature control, the precision reaches $\pm 0.1^{\circ}\text{C}$, far superior to the $\pm 0.5^{\circ}\text{C}$ of traditional control systems. In flow measurement and control, the precision can reach 0.2% of full scale, ensuring the accuracy of formulation control. In production process control, the batch pass rate increased from 95% to 98.5%. The system has advanced fault diagnosis capabilities, with the average fault detection time reduced to less than 2 minutes. The system availability is as high as 99.99%, with annual downtime controlled within 8 hours. In terms of communication performance, the system supports up to 16 industrial communication protocols, with a data acquisition cycle as fast as 10 ms. A single control station can handle up to 2000 process variables, effectively ensuring real-time monitoring and optimized management of the production process.

Table 1. Comparison of System Performance Indicators

Control Indicator	Traditional Control System	UW500 System	Improvement Effect
Temperature Control Precision	$\pm 0.5^\circ \text{C}$	$\pm 0.1^\circ \text{C}$	80% improvement
Flow Control Precision	0.5% F.S	0.2% F.S	60% improvement
Batch Pass Rate	95%	98.50%	3.5% improvement
Fault Detection Time	10 minutes	2 minutes	80% reduction

3. Pesticide Formulation Production Process Analysis

3.1. Process Flow and Control Requirements

The pesticide formulation production line primarily produces emulsifiable concentrate (EC) formulations. The production process involves steps such as material weighing, pre-mixing, emulsification, blending, and filling. In practice, the UW500 high-precision weighing module is used for raw material weighing, achieving a weighing accuracy of $\pm 0.1\text{kg}$, significantly higher than the $\pm 0.5\text{kg}$ accuracy of manual weighing. As shown in Figure 1, the temperature during the

mixing process is controlled within a range of $35\pm 0.5^\circ\text{C}$, the stirring speed is maintained at $450\pm 5\text{rpm}$, and the mixing time is precisely controlled for 30 minutes[5-6]. The emulsification step uses a high-speed emulsifier with the speed controlled at 3000rpm, the emulsification temperature maintained at $55\pm 1^\circ\text{C}$, and the emulsification time set for 45 minutes. The emulsification effect is monitored in real-time using an online particle size analyzer to ensure the particle size is controlled within a range of 2-5 microns. The filling process uses quantitative filling control, with an accuracy of $\pm 0.2\%$, which is a 50% improvement over traditional filling methods.

Key Process Control Parameters Trend Chart for Pesticide Formulation Production

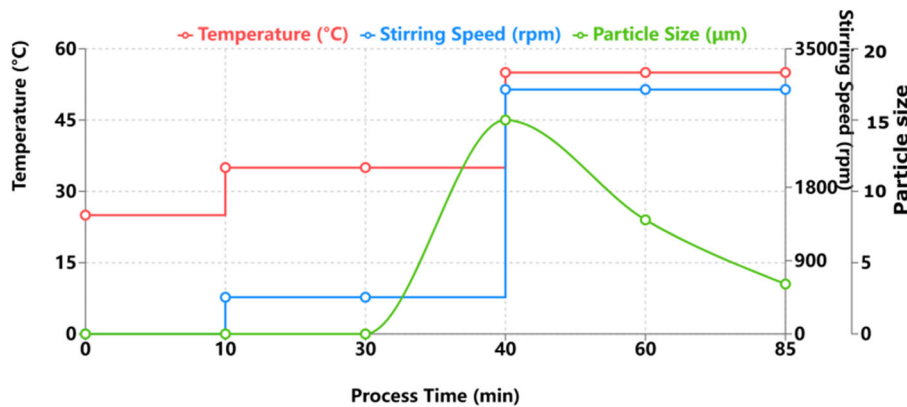


Figure 1. Trend Chart of Control Parameters for Key Steps in Pesticide Formulation Production

3.2. Quality Control System

Relying on the real-time monitoring and data acquisition functions of the UW500 system, a full-process quality control system has been established. Online detection equipment is used to monitor raw material quality indicators in real-time, and a complete electronic batch record system has been set up. As shown in Table 2, production data from 2023 indicates that the raw material inspection pass rate reached 99.2%, a 2.3 percentage point improvement compared to before the system upgrade. Statistical process control methods are employed for process quality control, and key process parameters are

monitored and analyzed in real time[7]. The compliance rate of process parameters reached 98.5%. Intermediate product inspection is conducted using online analyzers, with testing data directly transmitted to the UW500 system, resulting in an 80% improvement in inspection efficiency. The final product inspection results showed that the first pass rate of products reached 97.8%, with inter-batch quality fluctuations reduced to within $\pm 1.5\%$, significantly improving product quality consistency. The system automatically generates batch analysis reports, enabling full traceability of product quality.

Table 2. Comparison of Quality Control System Performance (2023)

Quality Control Metrics	Before UW500 Implementation	After UW500 Implementation	Improvement
Raw Material Pass Rate	96.9%	99.2%	+2.3%
Process Parameter Compliance	95.0%	98.5%	+3.5%
First-Time Quality Pass Rate	94.5%	97.8%	+3.3%
Batch Quality Variation	$\pm 3.0\%$	$\pm 1.5\%$	-50%
Quality Inspection Efficiency	Baseline	180%	+80%

3.3. Safety and Environmental Protection Management

The UW500 system establishes a multi-layer protection mechanism for safety and environmental protection management. With 87 gas detection points distributed across the production area, the system continuously monitors the concentration of toxic and harmful gases. System records show that no gas exceedance events occurred in 2023, as shown in Figure 2. The data from the waste gas treatment system indicates that the treatment efficiency remains above 98%, with waste gas emissions meeting national standards by 30%. The safety interlock system responds in less than 100

milliseconds, effectively preventing safety hazards such as equipment overheating or overpressure. Environmental monitoring data is uploaded in real-time to the environmental monitoring platform, with COD, ammonia nitrogen, and other indicators meeting 100% compliance[8]. Analysis of the operational data for 2023 shows that the system processed 2,156 alarm messages, with 12 high-level alarms, all of which were handled within 30 seconds, ensuring the safe and stable operation of the production process. The number of emergency handling activations has decreased by 85% compared to before the upgrade, fully demonstrating the system's significant effectiveness in safety and environmental protection management.

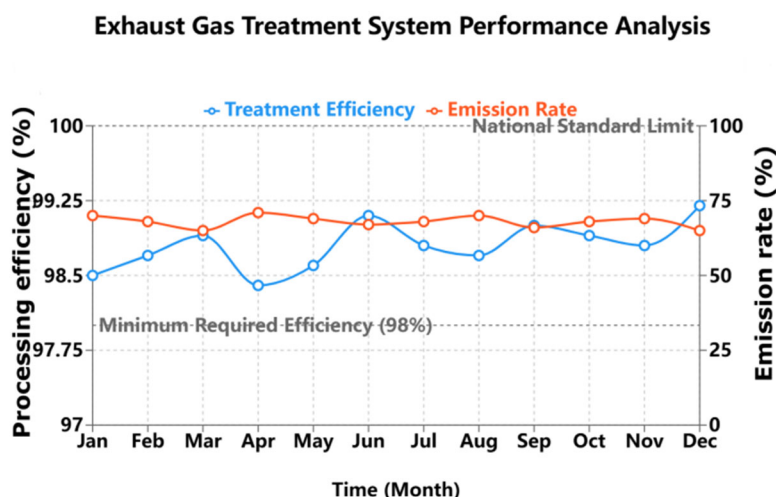


Figure 2. Trend of Waste Gas Treatment Efficiency

4. System Application Solution Design

4.1. Overall System Design

The UW500 system on this pesticide formulation production line adopts a three-tier network architecture, covering the field layer, control layer, and management layer. The field layer is equipped with 128 intelligent instruments, interconnected by a redundant fiber optic ring network with a network response time of less than 10ms. The control layer is configured with 4 UW563 redundant controllers, each handling 500 I/O points, with CPU load kept below 65%, ensuring control performance. There are 4 operator stations and 2 engineer stations, located in the central control room and the on-site control room. The system servers use a dual-machine hot standby solution, with a historical data retention period of 2 years and a data compression rate of 85%[9]. The system's overall network bandwidth utilization is kept below 50%, ensuring real-time and reliable data transmission.

4.2. Process Control Scheme

Based on the process requirements, 178 control loops were designed, including 45 single-loop PID controls, 23 cascade controls, and 12 ratio control loops. The temperature control loop uses an adaptive PID algorithm, with the overshoot controlled within 0.5°C at the 35°C operating point, and the adjustment time reduced to 90 seconds. The flow control loop

is equipped with feedforward compensation, with a dynamic response time of less than 5 seconds and control accuracy reaching 0.2% of the full scale[10]. The batch management system can simultaneously handle 8 batch production tasks, with a formula execution accuracy of 100%, and the batch switching time reduced from 30 minutes to 10 minutes. The sequence control program includes 86 control steps, with step switching time of less than 1 second, effectively ensuring the continuity and stability of the production process.

4.3. System Configuration and Monitoring

The system configuration design includes 32 process flow screens, covering all production units and auxiliary systems. The screen refresh cycle is set to 1 second, with the CPU usage kept below 45%. The trend curves record 1,024 process variables with a 1-second sampling cycle, and data compression algorithms reduce storage space requirements by 70%, as shown in Figures 3 and 4. The alarm system is divided into 4 levels, with 2,456 alarm points set, and the average alarm response time is less than 3 seconds. The real-time database capacity reaches 1 million points, and the historical data query response time is controlled within 5 seconds. Operator permissions are divided into 5 levels, with the retention period for key operation records extended to 3 years to meet production traceability requirements[11]. The system's average mean time between failures (MTBF) is 8,760 hours, and its operational reliability reaches 99.99%.

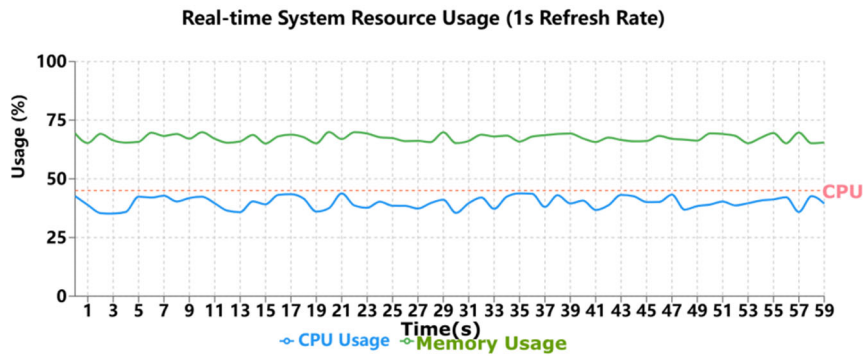


Figure 3. System Resource Usage Trend

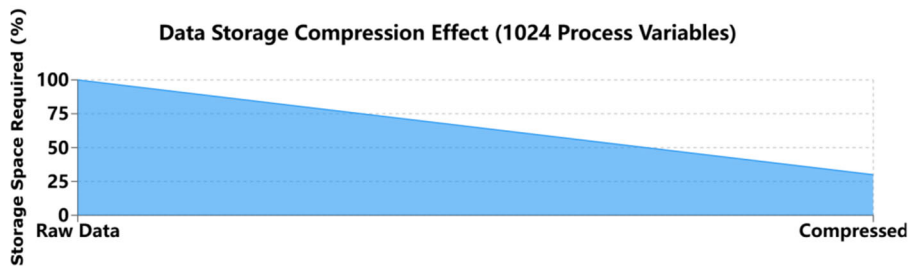


Figure 4. Data Compression Effect

4.4. Safety Control and Interlocking

The safety control system uses an independent UW563 safety controller, configured with 367 safety interlock points. The emergency shutdown system has a response time of less than 100ms, with a 100% annual testing pass rate. The equipment interlock protection covers 128 key devices, including 76 temperature interlock points, 54 pressure interlock points, and 38 level interlock points. System records

show that in 2023, the safety interlock was triggered 156 times, including 145 warnings for hazardous conditions and 11 emergency shutdowns, with no incidents of personnel injury or equipment damage, as shown in Figure 5. The dual-redundancy design of the interlock logic ensures that the system can still perform protection functions in the event of any single-point failure. Since the system was put into operation, its Safety Integrity Level (SIL) has always remained at SIL2[12].

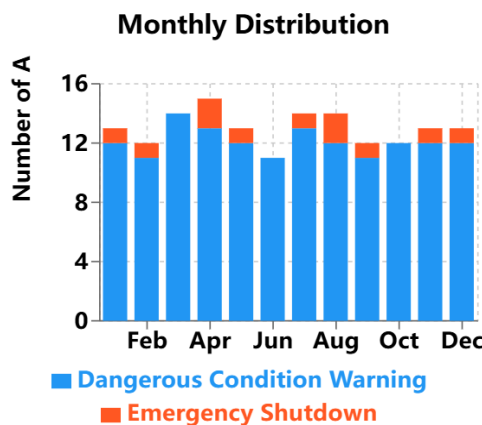


Figure 5. Detailed Distribution of Monthly Interlock Triggers

5. System Implementation and Application Effects

5.1. System Implementation Process

The UW500 system implementation project took 6 months and was divided into three stages: design, installation, and commissioning. The design phase completed the system hardware configuration and software scheme design, taking 45 days. The installation phase involved equipment

installation, instrument calibration, and network wiring, taking 60 days. A total of 128 intelligent instruments were installed, and 3.2 kilometers of optical fiber network were laid, completing the wiring and calibration of 2,456 I/O points. The commissioning phase was divided into single-machine debugging and online debugging, taking 75 days, and involved tuning and optimization of 178 control loops. Prior to system commissioning, a 15-day operator training session was organized, with a passing rate of 98%. During trial operation, the failure rate was below 0.1%, and the

commissioning completion rate reached 100%, with all performance indicators meeting design requirements.

5.2. Key Control Point Application Analysis

Continuous optimization was carried out for key control points in the production process. The temperature control loop underwent three parameter adjustments, improving the control accuracy from $\pm 0.5^{\circ}\text{C}$ to $\pm 0.1^{\circ}\text{C}$ and reducing the adjustment time from 180 seconds to 90 seconds. The material weighing system adopted a dynamic compensation algorithm, improving the measurement accuracy to $\pm 0.1\text{kg}$, far better than the design specification of $\pm 0.2\text{kg}$ [13-14]. In

the emulsification process, online particle size analysis and automatic adjustment reduced the product particle size distribution range from 5-10 microns to 2-5 microns, significantly improving product quality, as shown in Table 3. The filling accuracy was improved to $\pm 0.2\%$ through intelligent compensation control, reducing batch-to-batch error by 80%. Over the course of one year after system commissioning, the stability of key control points significantly improved, process fluctuations were greatly reduced, and product quality consistency was effectively ensured.

Table 3. Changes in Particle Size Distribution of Emulsification Process

Item	Particle Size Distribution Before Emulsification	Particle Size Distribution After Emulsification	Change Situation
Particle Size Range	5-10 microns	2-5 microns	Reduced by 3-5 microns
Median Particle Size	7.5 microns	3.5 microns	Reduced by 4 microns
Particle Size Standard Deviation	± 1.5 microns	± 0.8 microns	Improved by 0.7 microns

5.3. System Operation Effect Evaluation

Over the course of one year of operation, statistical analysis of operational data shows significant improvements in multiple aspects of the system. The control indicators of the production process have been significantly enhanced, with the system's availability reaching 99.99%. The annual unplanned downtime was only 8 hours, a reduction of 85% compared to before the upgrade. The first-pass product quality rate improved from 95% to 98.5%, and batch-to-batch quality fluctuation was significantly reduced to $\pm 1.5\%$. Additionally, the compliance rate of process parameters reached 98.5%, an improvement of 5 percentage points compared to before the upgrade, reflecting the increased stability and precision of the

production process. As shown in Figure 6, key indicators in the production process have met the expected goals. The safety interlock system passed the annual test with a 100% success rate, successfully preventing 12 equipment failures and avoiding potential major safety incidents[15]er batch from 8 hours to 6 hours, thereby increasing annual production capacity by 2,000 tons. Feedback from operators also reflects the system's efficiency, ease of operation, and reliability, with satisfaction rates above 95%. Overall, the system's implementation has not only significantly improved production efficiency and product quality but also effectively ensured production safety, increased operator satisfaction, and laid a solid foundation for the company's long-term development.

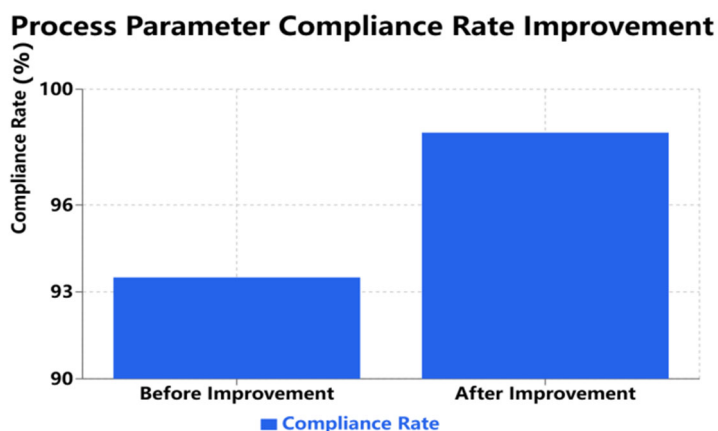


Figure 6. Improvement in Compliance Rate of Process Parameters

5.4. Economic Benefit Analysis

The total project investment was 5.8 million RMB.

Analysis of one year of operation data demonstrates the significant economic benefits of the system. Annual production capacity increased by 2,000 tons, generating an

additional output value of 40 million RMB. The improvement in product qualification rate directly drove the growth in economic benefits, producing approximately 2 million RMB in direct economic benefits. Energy consumption was reduced by 15%, saving 1.8 million RMB annually, demonstrating the optimization effect of the system on resource utilization. Maintenance costs were reduced by 60%, saving 850,000 RMB annually[16]. The reduction in labor costs also brought noticeable economic benefits to the company, with labor costs decreasing by 30%, saving 1.2 million RMB in annual wages. The significant reduction in equipment failure rate (a decrease of 70%) effectively reduced production downtime, saving approximately 1.5 million RMB in lost production annually,

ensuring the stability and continuity of production, as shown in Figure 7. Overall, the project generated an average annual new benefit of 7.35 million RMB after implementation, with a payback period of less than 10 months, far exceeding the expected goals. This indicates that the system not only effectively improved production efficiency and product quality but also significantly reduced operating costs. The successful implementation of the project has not only brought considerable economic benefits to the company but also yielded significant social benefits, providing valuable experience and a successful example for future intelligent transformation projects.

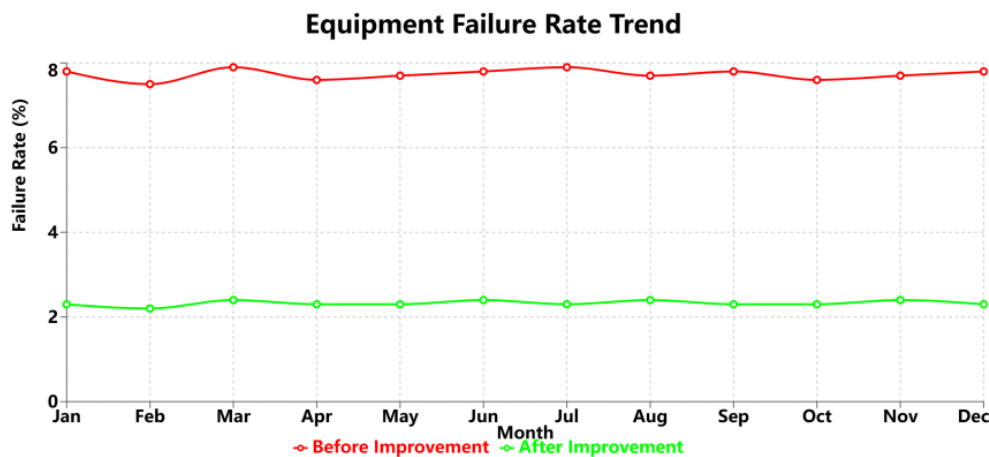


Figure 7. Trend in Equipment Failure Rate

6. Conclusion

The application of the UW500 series Distributed Control System (DCS) in the automation of pesticide formulation production has significantly improved the automation level and control precision of the production process. Key process parameters, such as temperature control accuracy of $\pm 0.1^{\circ}\text{C}$, product first-pass yield of 98.5%, and system availability of 99.99%, have all achieved breakthroughs. In terms of economic benefits, the project generates an average annual additional benefit of 7.35 million RMB, with a payback period of less than 10 months. However, the study also found areas for improvement in network security protection and artificial intelligence optimization control. In the future, the system could be further optimized by introducing deep learning algorithms to enhance control strategies and constructing a more comprehensive network security protection system, further improving the system's intelligence and operational safety. This research provides practical insights for the automation transformation of pesticide formulation production and has significant implications for promoting intelligent manufacturing in the industry.

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