Automated Vacuum System for Fette Tablet Machine Module

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Abstract

This study details the theoretical design and implementation of an automated vacuum control system developed to enhance particle removal efficiency in pharmaceutical manufacturing environments. The system integrates sensor feedback, programmable logic control (PLC) and real-time monitoring to optimize vacuum performance, minimize manual intervention and maintain GMP-compliant cleanroom conditions. The research demonstrates how automation improves process reliability, contamination control and regulatory adherence within pharmaceutical production facilities.

Background

Pharmaceutical manufacturing requires strict contamination control, as airborne and process-generated particles can compromise product quality. Traditional vacuum systems often rely on manual operation, leading to inefficiencies and inconsistent performance. With growing regulatory demands and the industry's shift toward automation, integrating PLC- and VFD-based control systems has become essential to enhance cleanliness, energy efficiency, and compliance with GMP and FDA standards.

Problem

Maintaining cleanliness and preventing cross-contamination in pharmaceutical manufacturing is essential to comply with GMP, ISO, and FDA standards. Conventional vacuum systems lack automation, adaptability and data integration, leading to higher energy use, inconsistent performance, and increased manual intervention. There is a need for an automated vacuum control system that enhances particle removal efficiency, reduces operational variability and ensures regulatory compliance within cleanroom environments.

Methodology

The project followed a three-phase approach: system requirement analysis, design and automation architecture, and validation testing. A PLC-based control system with integrated pressure and airflow sensors was developed, modeled in CAD and connected through SCADA for monitoring and alarms, as shown in Figures 1–4. The prototype was validated in a pilot cleanroom using Excel to compare energy efficiency, reliability and regulatory compliance between manual and automated systems.

Methodology (cont.)

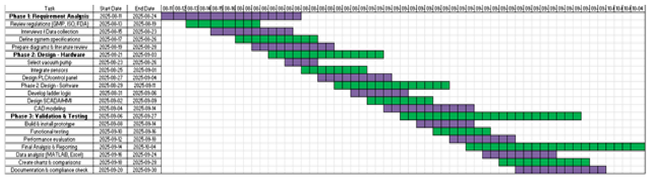


Figure 1
Project Gantt Chart

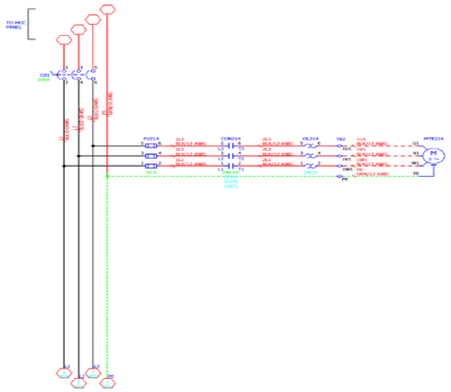
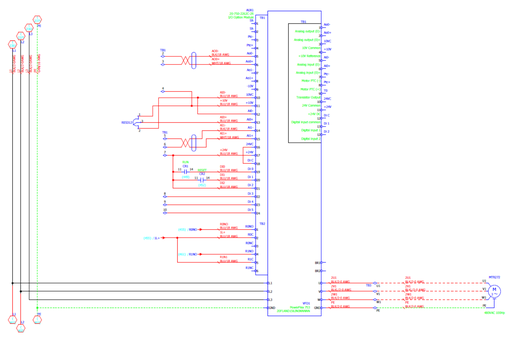


Figure 2
Electrical Diagram of Automated Circuit



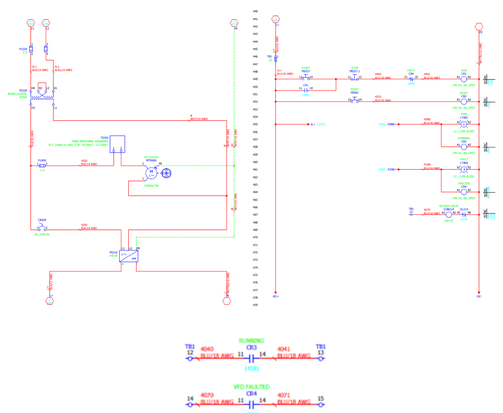


Figure 2
Electrical Diagram of Automated Circuit
(Continuation)

Results and Discussion

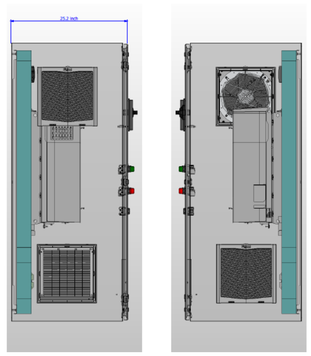


Figure 3
Side View of Electrical Cabinet

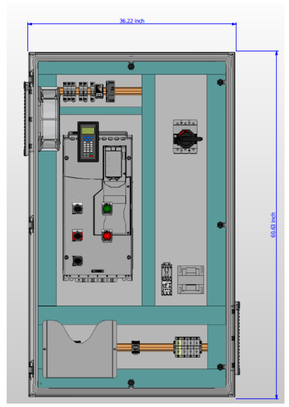


Figure 4
Front View of Electrical Cabinet

The automated VFD-based system achieved up to 40% energy savings, improved pressure stability, and reduced mechanical wear. Tables 1–2 show clear gains in efficiency, responsiveness and reliability compared to the manual setup. PLC–SCADA integration enhanced monitoring and compliance with GMP and FDA 21 CFR Part 11, confirming the system's suitability for modern, energy-efficient pharmaceutical operations.

Parameter	Contactor-Based System	VFD-Based System
Average Power Consumption	3.5 kW	2.1 kW
Operating Time per Cycle	100% (Always ON)	~60–70%
Energy Savings	-	~35–40%

Table 1
Energy Comparison Between Configurations

Metric	Contactor System	VFD System
Response Time to Load Change	7.7 seconds (Avg)	1.92 seconds (Avg)
Pressure Stability Range	±15%	±5%

Table 2
Response Time and Pressure Stability between Configurations

Conclusions

The implementation of a VFD-based automated vacuum system significantly improved energy efficiency, reliability and process control in pharmaceutical manufacturing. By integrating PLC, SCADA and real-time monitoring, the design achieved up to 40% energy savings, reduced mechanical wear and enhanced regulatory compliance under GMP and FDA 21 CFR Part 11. This project demonstrates how automation supports sustainable operations, minimizes cross-contamination risks, and advances Industry 4.0 readiness in pharmaceutical environments.

Future Work

Future development will focus on integrating AI-driven predictive maintenance, cloud-based monitoring and energy recovery systems to enhance efficiency and reliability. The design will be expanded to other unit operations and coupled with renewable energy sources to support Industry 4.0 and sustainable pharmaceutical manufacturing.

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