SMART AUTOMATION: ENHANCED EFFICIENCY AND REAL-TIME OPTIMIZATION FOR SOLVENT PROCESS

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ABSTRACT

Solvent-based cleaning is essential in high-precision industries such as hard disk drive (HDD) and semiconductor manufacturing, where even minimal contamination can compromise product reliability. Traditional cleaning systems rely on fixed settings and manual oversight, often resulting in inefficiencies and inconsistent outcomes.

To address these limitations, a smart automation system was developed using real-time sensors and programmable logic controllers (PLCs) in a closed-loop configuration. The system monitors key parameters—temperature, solvent level, ultrasonic power, and bath life—and applies data-driven algorithms for adaptive control and predictive maintenance, enabling a shift from schedule-based to condition-based operation.

The system achieved 90% stable in ultrasonic power energy for more than the defined routine calibration schedule, ensuring consistent cleaning performance. Overall, Tool availability is approximately 90%, reflecting a 16% gain over manual methods. Predictive alerts minimize unplanned downtime, and real-time monitoring allows tighter control of critical cleaning parameters.

This study presents a scalable, intelligent solution for modernizing solvent cleaning through proactive contamination control and smart automation.

1. 0 INTRODUCTION

Solvent cleaning is the process of removing contamination from a surface without physically or chemically altering the material being cleaned. This includes various methods, such as ultrasonic cleaning, immersion, or vapor drying[1].

Traditionally, data collection and monitoring, such as temperature, Ultrasonic power, and bath life, rely on manual data monitoring using Excel. Filter replacement is by scheduled preventive maintenance, and ultrasonic generator calibration routines are based on the vendor's recommendation. This approach often lacks the detailed, real-time data needed for precise process control.

The Fourth Industrial Revolution (4IR) began with digital technology to tackle complex manufacturing. It uses real-time data collection, processing, and analysis with advanced algorithms to optimize operations, boost efficiency, and meet strategic goals[2]. Using this 4IR concept, the solvent process will address this old approach through the smart sensing technology that is linked with the Internet of Things (IOT), which extends beyond the non-network sensors capable of advanced functionality[3].

To tackle this challenge, the proposed solvent cleaning smart system integrates several core components

1.1 The Sensing Unit/Module

Deployed to capture real-time data on the key parameters like temperature, chemical level, ultrasonic power, and cleaning bath usage.

1.2. Programmable Controllers

Utilizes platforms such as Omron, Siemens and Mitsubishi for real-time data acquisition, signal processing, and actuator control.

1.3. Real-Time Control Feedback System

Implements a Feedback loop mechanism for identified parameters through email notification.

1.4. Human-Machine Interface (HMI)

Provides users with visual dashboards, manual override capabilities, and system diagnostics. Cloud Integration: Enables remote data access, storage, and analytics for long-term process improvement.

2. 0 REVIEW OF RELATED WORK

See 1.0 INTRODUCTION

3.0 METHODOLOGY

This study focuses on implementing a smart automation system in the solvent-based cleaning process, aimed at improving the consistency, reliability, and overall performance through the transition from Manual to automated by the integration of IOT/Smart Automation System. The methodology is structured around three key areas: parameter measurement, variation tracking, and statistical analysis.

3.1 Integration of IoT/Smart Automation System

To integrate into smart automation, an OPC (OLE for Process Control) (OLE: Object Linking and Embedding) is installed into the tool, interlinking the PLCs (Programmable Logic Controllers) to convert the PLC data into engineering values. The gathered data was then stored on a Host PC (Personal computer) and uploaded to the cloud through the database. A webpage is used as the reference for the users to monitor the defined KVI's (key input variables), tool alarms and email notifications. The automation framework in Fig. 1 is built on a feedback-driven IoT architecture, where real-time data from sensors is captured and processed by embedded controllers

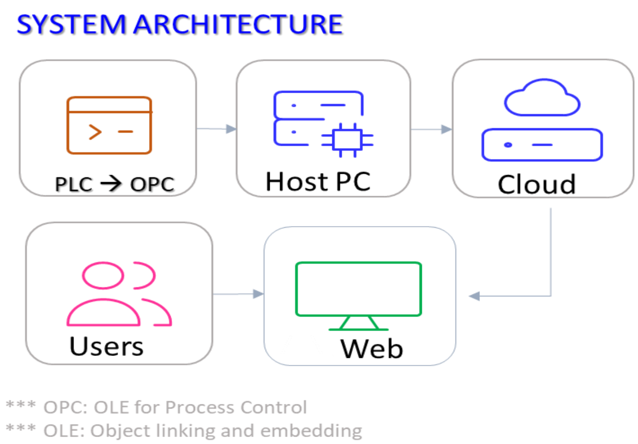

Fig. 1. Smart Automation Structure of Solvent Cleaning

3.2. Transition from Manual to Smart Automation

From the traditional data gathering and using the preventive maintenance results through checking, cleaning, and replacement. The manual logging and reactive maintenance are replaced by a proactive approach that includes an e-recording module for secure digital logging of all process parameters, alarms, and maintenance actions. This IoT-enabled/smart system marks a significant shift from manual oversight to intelligent automation in the solvent cleaning process [3]. These combined approaches of real-time measurement, automated control, and statistical analysis guarantee a predictive, data-driven solution for solvent cleaning.

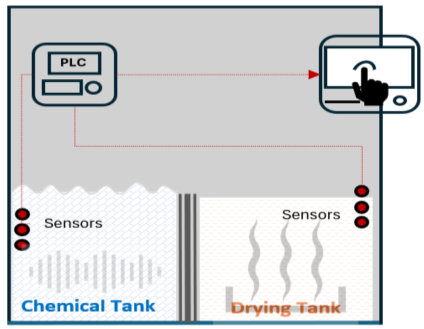

Fig 2: Manual set-up of Solvent cleaning, where the sensors feed data into the PLC and are monitored through the HMI (Human-Machine Interface)

4.0 RESULTS AND DISCUSSION

The implementation of the Smart Automation System for solvent cleaning has proven effective, as demonstrated by the Statistical Process Control (SPC) chart data, which shows consistent process control within specified parameters. Key performance indicators, including temperature stability maintained within target ranges and ultrasonic power achieving 90% consistency, indicate that the data collected is reliable. Replaced the conventional schedule- and routine-based filter replacement approach with a predictive maintenance system as shown in Figure 3, resulting in 50% savings from 8 units to 4 units of the filter consumption and Ultrasonic calibration frequency interval.

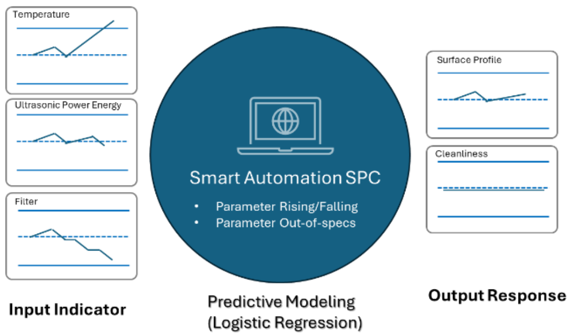

Fig. 3: Algorithm of Solvent Cleaning Predictive Maintenance

Additionally, improvements in Overall Equipment availability and a reduction in bath replacement frequency further support the system's positive impact. These results provide sufficient evidence to confirm that smart automation enhances solvent cleaning performance. However, continued implementation and across broader datasets would further substantiate the system's long-term effectiveness and operational reliability.

The following capabilities represent key enhancements achieved in the transition from manual processes to smart automation.

4.1. KIV Trend

These charts show the logged data every minute with or without the parts process to monitor the tool performance. This enables the users to react proactively. Fig. 4 shows the sample critical KIV trend.

Fig. 4. Example of a KIV trend chart

4.2. Statistical Process Control (SPC)

Real-time SPC charts are used to monitor trends and variation in key parameters (e.g., temperature stability), helping detect deviations or drifts early. Fig. 5 illustrates an SPC chart of solvent temperature. These include mean, range, and standard deviation, which are employed to quantify and contrast process behavior under manual and smart automation.

Fig. 5. Shows the Solvent Process Temperature SPC trend

4.3. Email Notification

In addition to on-tool alarms, the smart automation system sends email notifications to users. Fig. 6 illustrates an alarm notification. This feature ensures that maintenance personnel can respond promptly to issues, even when they are not physically present at the production line.

Fig. 6. Sample alarm notification

4.4. Tool Availability

This demonstrates the effectiveness of the system in reducing bottlenecks and improving tool availability from 77% to 90%.
Improvements in availability result in a more stable baseline, which in turn results in more predictive quality, as shown in Figure 7.

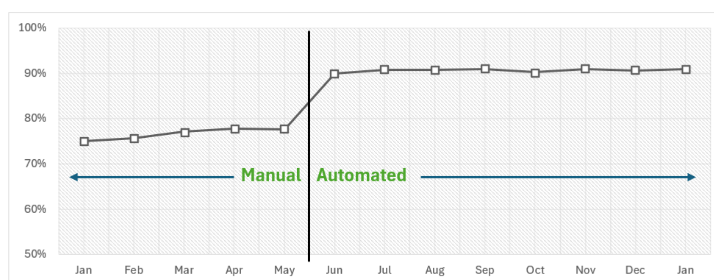

Fig. 7. Process Availability Before and After the Smart Automation

4.5. Ultrasonic Power

Smart Automation in Fig.8 has proved that ultrasonic power is still efficient beyond the traditional routine procedure, showing a 90% Ultrasonic Power stability.

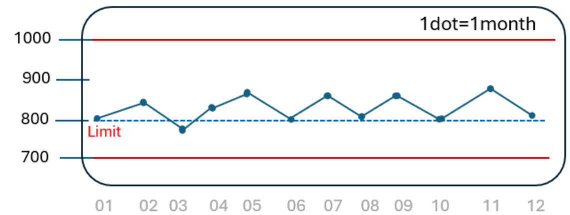

Fig. 8. Stable Ultrasonic Power rating for more than the routine schedule

4.6. Filter Differential Pressure

The filter pressure delta in Fig. 9 shows the consistency of filter differential pressure without degradation of contamination through visual inspection.

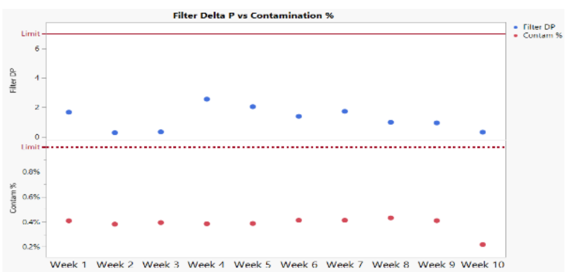

Fig. 9. Filter differential pressures. the contamination result

5.0 CONCLUSION

The smart automation system has successfully achieved its primary objectives of enhancing process control and monitoring capabilities. Key achievements include: 90% ultrasonic power stability, a 16% improvement in Overall tool availability, 50% savings of the filter consumption and Ultrasonic calibration frequency interval.

6.0 RECOMMENDATIONS

Expand system capabilities to include additional cleaning parameters. Integration of the tool interdiction and application to all similar cleaning tools in the production lines.

7.0 ACKNOWLEDGMENT

We extend our sincere gratitude to Western Digital Philippines Corporation for their support and resources. Special thanks to.
Roger Pabuaya, Aileen Jara, Noel Maliksi

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