

IoT-Based Early Fault Detection System for Dust Collectors in Commutator Cutting Machinery

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Received: 27 July 2025

Accepted: 19 September 2025

Abstract

This study aims to reduce machine downtime and increase production efficiency by developing an IoT-based early fault detection system for the dust collector of a commutator cutting machine at PT XYZ, an Indonesian automotive component manufacturer. The system addresses recurring issues related to insufficient suction pressure and copper powder buildup, which previously led to defective products and production interruptions. Using a prototype-based development approach, the system integrates real-time pressure monitoring, automatic tube switching, and visual-audio alerts to ensure stable operational performance. Sensor data are displayed locally on an LCD and remotely through a ThingsBoard dashboard, enabling rapid operator response. Validation results indicate fast data transmission with an average latency below 0.10 seconds, effectively preventing operational disruptions and reducing defective output. System implementation resulted in weekly production time savings of 30 minutes, the elimination of 100 defective units per month, and improved preventive maintenance supported by usage counters for filters and hoses. This work demonstrates the potential of IoT-based monitoring systems as scalable, data-driven, and cost-effective solutions for enhancing machine reliability and product quality.

Keywords

Internet of Things, Preventive Maintenance, Industrial Machine, Inductive Proximity Sensor, HX710B, MQTT ThingsBoard.

Introduction

The growth of the modern manufacturing sector demands effective production strategies, particularly the application of preventive maintenance to maintain machine reliability. Preventive maintenance helps avoid unexpected failures that may cause downtime and reduce production output (Rakes David, 2024).

In industrial environments, the Internet of Things (IoT) has become a key technology for increasing operational efficiency. Its industrial implementation, known as the Industrial Internet of Things (IIoT), enables extensive connectivity and real-time data acquisition to support better decision-making processes (Bányai & Bányai, 2025).

PT. XYZ is an Indonesian manufacturing company specializing in automotive replacement parts, including armatures. The N100 armature productionline experienced performance limitations, causing downtime and reduced productivity. A defect report from December 2024 recorded the following issues:

- Resistance Assessment: 100 units (50%)
- Welding Sparks: 40 units (20%)
- Wire Break: 36 units (17%)
- Balancing Error: 19 units (13%)

For optimal performance, a single production shift of 8 hours (28,800 seconds) should yield 4,800 units at 6 seconds per unit. However, the presence of 200 defective units reduces performance to 95.8%.

A Pareto analysis of downtime shows that resistance inspection failures are the largest contributor. These failures are primarily caused by copper dust residue trapped between commutator segments after cutting. Insufficient suction pressure occurs when the dust collector's waste container exceeds capacity, causing blockages and reduced airflow. As a result, copper particles adhere to commutator surfaces, producing non-conforming products.

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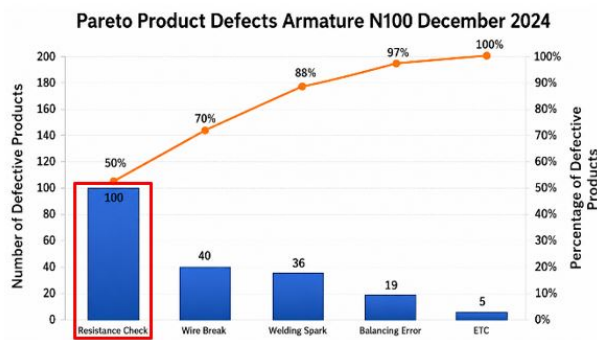


Fig. 1. Pareto diagram data for December 2024

The data clearly indicates that resistance inspection failures constitute the predominant Pareto element, severely impacting downtime and productivity loss. The issues stem from the insufficient operation of the commutator cutting machine, primarily caused by residual copper dust particles remaining between commutator segments after cutting.

The particles are inadequately vacuumed because the dust collector's waste container has surpassed its capacity, resulting in diminished suction pressure owing to obstruction. As a result, the dust adheres to the treated commutator surfaces, leading to non-good products.



Fig. 2. Quality Product

Given the preceding context, a device is required for the real-time monitoring of the dust-collecting container state and suction pressure performance of the dust collector system on the commutator cutting machine to identify abnormal circumstances. An IoT-based early damage detection system for the dust collector and dust storage container can facilitate this objective. The implementation of this system is anticipated to resolve these challenges and enhance productivity on the production line at PT. XYZ (Lee et al., 2022).

This study introduces a novel preventive maintenance system based on IoT technologies, integrating HX710B pressure sensors and LJ12A3-4-Z proximity sensors to monitor suction performance and dust container capacity in real time. The system is built using an ESP8266 microcontroller and the ThingsBoard platform for data visualization, and it features automated filter cleaning and container switching without

requiring operator intervention. Unlike conventional approaches that rely on manual inspection or limited monitoring capabilities, this system enables early anomaly detection and data-driven decision-making through real-time analytics. The novelty of this research lies in its application of an integrated monitoring and control system specifically designed for commutator cutting machines—an implementation not previously explored in the context of Indonesia's automotive manufacturing sector. The proposed solution enhances operational efficiency, extends component lifespan, and significantly reduces the risk of unplanned downtime.

Literature review

A literature review was conducted to support the system design and implementation, covering IIoT concepts, preventive maintenance approaches, commutator cutting mechanisms, sensor selection, and system architecture.

Industrial Internet of Things

The IIoT integrates industrial equipment with sensors, software, and networks to enable automated data collection and enhanced processing. This connectivity streamlines operations and improves product quality by enabling real-time monitoring of environmental and operational variables (Saqlain et al., 2019).

The advantages of the IIoT encompass enhanced productivity and a substantial influence on the quality of manufactured items. Manufacturers can monitor environmental and operational variables that directly impact product quality by utilizing sensors and smart devices across the manufacturing line (Wójcicki et al., 2022).

Preventive Maintenance

Preventive maintenance (PM) is a strategy that aims to prevent equipment failure by addressing potential degradation in performance before breakdowns occur. Its primary objective is to improve equipment availability and maintain optimal operational efficiency (Alamri & Mo, 2023).

PM principles are generally divided into two categories: Time-based maintenance, which schedules maintenance at predetermined intervals.

Condition-based maintenance, which monitors the actual condition of equipment using sensor data and performs interventions only when necessary (Ali & Abdelhadi, 2022).

Commutator Cutting Apparatus

The A commutator cutting machine is used to refine the copper commutator surface to achieve a smooth and precise finish. The commutator diameter typically decreases from 27 mm to 26 mm after machining.



Fig. 3. Commutator Cutting Machine



Fig. 4. Diameter Before and After Cutting



Fig. 5. Dust Collector

The dust collector attached to this machine functions to remove copper powder generated during the process. It operates within a suction pressure range of 0–10 kPa, with the following conditions:

- Normal: 0–2 kPa.
- Warning: 2–5 kPa.
- Emergency: 5–10 kPa.



Fig. 6. Filter Dust Collector

Dust collectors comprise various primary components, including:

- Filter or filtration media: Employed to segregate dust particles from the airflow.
- Blower or fan: Generates airflow that attracts particles into the system.
- Analog parameters are used to assess the suction power, which ranges from 0 to 10 kPa.



Fig. 7. Parameter Analog

- A container for collecting waste dust from commutator cutting.



Fig. 8. Powder Container

Waste powder storage is a facility designated for the accumulation of chips or waste generated from the comminution cutting process.

Types of Sensors and Microcontrollers

I utilize the HX710B sensor to measure air pressure, necessitating certain value thresholds to obtain the intended output. This sensor is a 24-bit ADC (analog-to-digital converter) engineered to accurately read minimal analog signals from sensors. The chip is frequently utilized alongside 0–40 kPa pressure sensors, especially those functioning on the concept of resistance variation (Gani et al., 2024).



Fig. 9. HX710B Sensor

The Proximity LJ12A3-4-Z is an inductive proximity sensor designed to detect metallic or copper items. The sensor can detect things at a maximum distance of 4 mm; hence, if the powder is airborne within the tube, the sensor will stay unaffected and will only register powder that has fallen within 4 mm beneath it (Yulia Basri et al., 2022).



Fig. 10. LJ12A3-4-Z Proximity Sensor

System Architecture Design

The early detection system was designed based on the identified need for real-time monitoring of machine conditions. Its IoT-based architecture includes pressure sensors, proximity sensors, a microcontroller for data processing, and wireless connectivity for cloud monitoring. All components operate in an integrated manner to provide early warnings of potential failures. This architecture enables real-time data acquisition and rapid operator response (Ungurean & Gaitan, 2020).

Sequence control in the IoT system refers to the ordered operation of sensors, actuators, and microcontroller functions. In this work, an Arduino microcontroller processes sensor input, controls actuators, displays data on an LCD, and transmits information to the cloud via ThingsBoard (Hsing-Chung Chen, 2022).

Data & Research Methods

Problem Identification

The N100 armature production line at PT XYZ has experienced a high number of non-conforming products, primarily caused by failures during the resistance inspection process. A Pareto analysis shows that the dominant factor is copper dust residue adhering to the commutator surface, resulting from inadequate suction performance of the dust collector.

The existing engine design operates under conditions that may lead to considerable downtime.

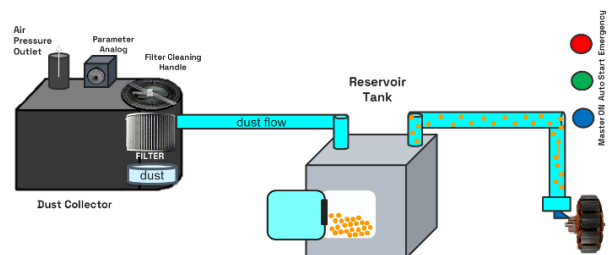


Fig. 11. Current Condition

Product Evaluation The standardization of product quality according to resistance measurement is 0.5000–0.6500. If the resistance measurement is outside the standard range, the product is deemed non-good.

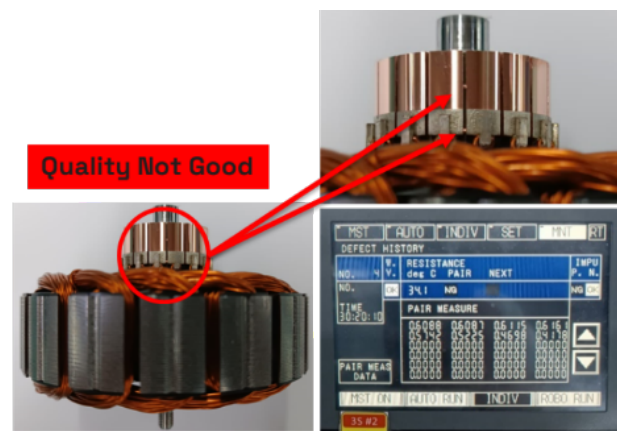


Fig. 12. Standardization of Quality Product

Two critical issues were identified:

- The copper dust chamber often exceeds its capacity due to the absence of a level detection system, leading to overflow and reduced suction efficiency.



Fig. 13. Uncontrolled Waste Powder Container

- The dust collector filter gradually clogs over time, lowering suction pressure. Without automated alerts, abnormal conditions go undetected, compromising system performance.



Fig. 14. Manual Dust Collector Condition without Warning

Proposed Solution

To resolve these problems, an IoT-based early fault detection system was developed consisting of two primary modules:

a. Powder Container Monitoring System

A proximity sensor-based level detection mechanism is implemented to monitor copper powder accumulation. When the first container reaches full capacity, the system automatically activates a secondary tube to divert the powder flow. This allows the first container to be emptied without halting the commutator cutting process, preventing downtime.

b. Dust Collector Suction Monitoring System

A digital pressure sensor (HX710B) is used to measure suction pressure within the specified ranges:

- Normal: 0–2 kPa;
- Warning: 2–5 kPa;
- Emergency: 5–10 kPa.

Previously, the operator needed to manually rotate a handle to clean the filter during warning conditions. In the proposed system, this handle is replaced with an SG90 servo motor that automatically rotates the cleaning mechanism when required, improving efficiency and eliminating manual intervention.

Experimental Validation

The system development follows a prototyping methodology. The prototype serves as an initial representation of the final system, enabling rapid evaluation and refinement of design concepts before full-scale implementation (Bjarnason et al., 2023).

The prototype includes essential system components but is not required to match industrial performance standards. It primarily aims to validate user requirements, detect design flaws early, and assess overall feasibility.

Hardware Components:

- HX710B Pressure Sensor.
Measures air pressure in the dust collector channel.
- LJ12A3-4-Z Proximity Sensor.
Detects copper powder levels inside the storage tube.
- Arduino Mega 2560.

Processes sensor data, controls the servo motor, LED indicators, and buzzer, and transmits data to both the LCD and ThingsBoard.

- SG90 Servo.

Motor Handles automatic switching of airflow between tubes and filter-cleaning mechanisms.

- LED Indicators & Buzzer.

Provide visual and auditory alerts of system status.

- 204 LCD Module.

Displays real-time pressure values, tube levels, and operating status.

- ESP8266 Wi-Fi Module.

Sends sensor data to the ThingsBoard dashboard for remote monitoring.

System Features:

- Real-Time Pressure Monitoring.

The system continuously measures suction pressure using the HX710B sensor. Deviations may indicate blockages, leaks, or filter clogging.

- Tube Level Monitoring The proximity sensor detects copper powder levels at 25%, 50%, 75%, and 100%. At full capacity, the system automatically switches the tube.

- Automated Valve Control The servo motor regulates the airflow path based on tube status.

- Visual & Audio Alerts

- Normal: 0–2 kPa → Green LED;
- Warning: 2–5 kPa → Yellow LED;
- Emergency: 5–10 kPa → Red LED + Buzzer.

- **Real-Time Data Presentation** Sensor values are displayed on the LCD and the ThingsBoard dashboard, enabling remote monitoring.

Critical data, including air pressure values and the status levels of tubes one and two, are presented in real time.

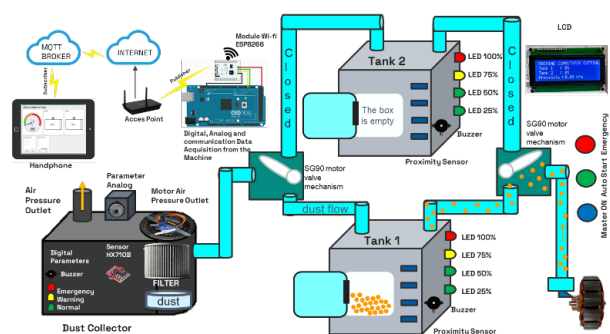


Fig. 15. Prototype Architecture Design Ideas

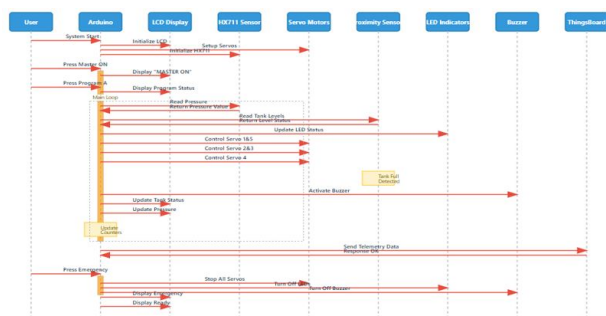


Fig. 16. Control Sequence Diagram

Upon validation of the prototype’s functionality, the system can be advanced into an industrial version utilizing more robust and dependable components while maintaining the fundamental architecture established by the prototype (Raposo et al., 2018).

The system concept undergoes early validation through prototyping. Fundamental features, including pressure detection, dust collector performance assessment, and data transfer over IoT, can be rapidly evaluated prior to complete installation (Gumilang Fajar, 2022).

System coding is the phase in which the sanctioned system design is converted into executable program code for a computer. This procedure entails utilizing programming languages that align with the system’s requirements and relevant standards (Nikolov et al., 2008).

Prototype Implementation

The prototype implementation stage involves assembling all primary components to validate the system’s

functional design. Each component is installed, wired, and tested individually before integration into the complete system.

Installation of Proximity Sensor and LED Indicators

The LJ12A3-4-Z proximity sensors are installed on tube one and tube two to detect copper powder levels. Each sensor is connected to corresponding LED indicators that represent the fill levels of the powder containers.

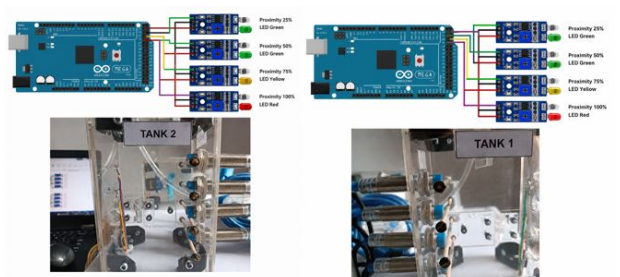


Fig. 17. Wiring Sensor and LED Tank One and Two

Installation of HX710B Pressure Sensor and LED Indicators

The HX710B pressure sensor is mounted on the dust collector’s suction line. Despite its high sensitivity and 24-bit ADC capability, the sensor is susceptible to temperature fluctuations, electromagnetic interference, and connector stability.

Calibration was performed at three reference points (1.4, 4.2, and 7.0 kPa), resulting in an average measurement deviation of ± 0.2 kPa, which falls within acceptable tolerance for monitoring applications.

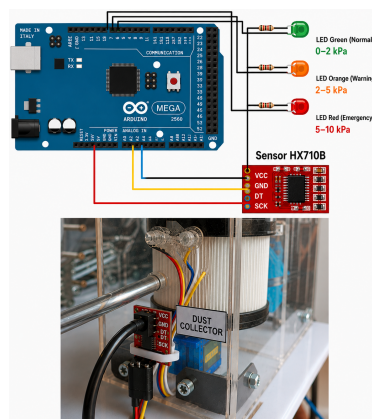


Fig. 18. Wiring HX710B Sensor and LED

Installation of Servo-Controlled Valves

Two SG90 servo motors were installed to function as automatic airflow diverters between tube one and tube two. The servo motors switch between containers once the corresponding sensor indicates a full capacity condition.

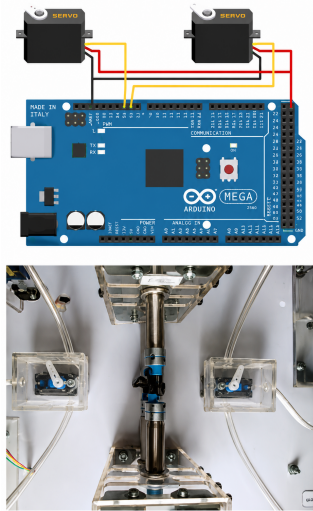


Fig. 19. Wiring Valves One and Two

Installation of Push Buttons

Three push buttons were integrated into the prototype:

- Master ON: simulates system power activation;
- Auto Start: executes the automatic program sequence;
- Emergency Stop: terminates all processes and resets the system.

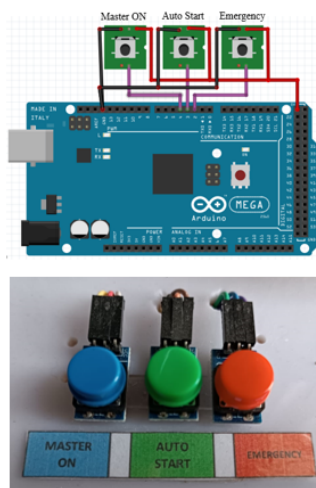


Fig. 20. Wiring Push Button

Installation of 20 × 4 LCD Display

An I2C-based 204 LCD module is installed to display:

- Pressure readings;
- Container level status;
- System mode (normal, warning, emergency).

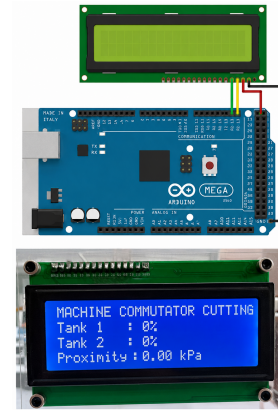


Fig. 21. Wiring LCD

Installation of Workpiece and Motor Simulation

Additional components were installed to simulate the rotation of the commutator workpiece and the dust collector motor for system demonstration purposes.

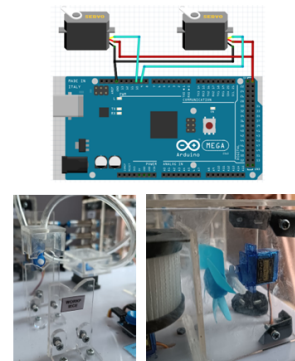


Fig. 22. Wiring Workpiece and Dust Collector Motor Simulation

Installation of ESP8266 Wi-Fi Communication Module

The ESP8266 module provides wireless connectivity for transmitting pressure and level data to ThingsBoard. A ThingsBoard dashboard was configured by generating an access token and embedding it into the Arduino code. Sensor and system parameters were mapped to the dashboard for real-time visualization.

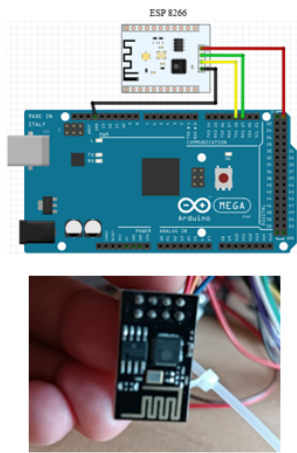


Fig. 23. Wiring ESP8266 Communication

Create a dashboard on ThingsBoard by integrating the utilized Wi-Fi network, then copy the access token and input it into the Arduino program. Modify the initialization of sensors and indicators to align with the configuration on the ThingsBoard, ensuring compatibility with the hardware and updates on the ThingsBoard dashboard for remote monitoring.

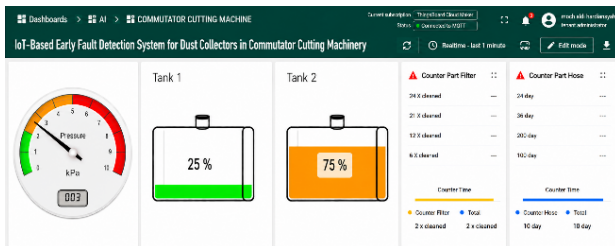


Fig. 24. Dashboard Thingsboard

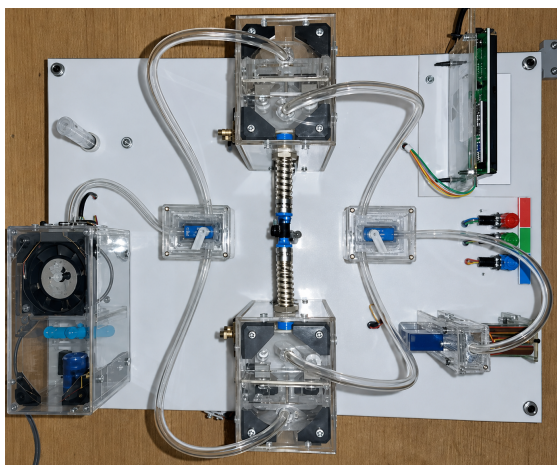


Fig. 25. Thingsboard Dashboard View and Prototype

Results

System testing seeks to verify that the developed system functions in accordance with specifications and is devoid of errors. The testing procedure encompasses multiple test categories, such as functional tests, performance tests, security tests, and usability tests. Each test type is intended to detect and rectify issues in various facets of the system (Nikolov et al., 2008).

Upon completion of the prototype implementation, testing is conducted to verify that all components and systems operate in accordance with the specified design criteria. Testing is conducted in phases on each primary component, followed by an assessment of the overall system integration.

Table 1
HX710B Pressure Sensor Testing

No	Pressure (kPa)	Status	LED Status and Thingsboard	Result
1	1.4	Normal	Normal	Pass
2	4.2	Warning	Warning	Pass
3	7.0	Emergency	Emergency	Pass

Table 2
LJ12A3-4-Z Proximity Sensor Testing

No	Level Powder Container One and Two	Status	LED Status and Thingsboard	Result
1	25%	Normal	Normal	Pass
2	50%	Normal	Normal	Pass
3	75%	Warning	Warning	Pass
4	100%	Emergency	Emergency	Pass

Table 3
SG90 Servo Motor Testing

No	Level Powder	Servo Status	LED Status and Thingsboard	Result
1	Container One 100%	Closing Tube One	Emergency	Pass
2	Container Two 100%	Closing Tube Two	Emergency	Pass

Table 4
Push Button Testing

No	Push Button	Program Status	Result
1	Master ON	Running Power	Pass
2	Auto Start	Running Program	Pass
3	Emergency	Reset Program	Pass

Table 5
Testing the ESP8266 Wifi Module in Sending Data

No	Key	Reading Time on Device	Reading Time on Dashboard	Time Difference	Result
1	Filter Counter	2025-06-29 11:26:21	2025-06-29 11:26:23	2s	Pass
2	Pressure	2025-06-29 11:26:21	2025-06-29 11:26:23	2s	Pass
3	Container One	2025-06-29 11:26:21	2025-06-29 11:26:23	2s	Pass
4	Container Two	2025-06-29 11:26:21	2025-06-29 11:26:23	2s	Pass
5	Container Counter	2025-06-29 11:26:21	2025-06-29 11:26:23	2s	Pass

Table 6
Filter and Hose Replacement Counter Data Testing

No	Label	Count	Actual Value	Max	Result
1	Part Filter	2025-06-29 11:26:22	2×	36×	Pass
2	Part Hose	2025-06-29 11:26:22	10 day	360 day	Pass

Technical Limitations and System Efficiency Evaluation

Although the system successfully demonstrates the intended functionality, several technical limitations were identified:

- Wi-Fi Interference** The ESP8266 is susceptible to signal interference in industrial environments with high electromagnetic noise. This may lead to delayed or missing updates on the ThingsBoard dashboard.
- Sensor Contamination** The inductive proximity sensor may experience reduced sensitivity if copper dust accumulates on its surface; periodic cleaning and recalibration are necessary.
- Servo Motor Durability** The SG90 servo motor used in the prototype is not designed for harsh industrial environments. A stronger servo or pneumatic actuator is recommended for long-term deployment.

The final implementation significantly improves the operational efficiency of the commutator cutting machine. With dual tube switching, continuous suction monitoring, automatic valve control, and multiple alert mechanisms, the system eliminates the routine 30-minute weekly downtime previously required for manual powder disposal.

Real-time monitoring via LCD and ThingsBoard improves operator awareness and supports timely preventive maintenance actions.

Advantages of the System and Efficiency of the Early Warning System

The implementation of the proposed IoT-based monitoring system provides several operational advantages. Previously, the commutator cutting machine operated with a single powder container, requiring a weekly 30-minute shutdown for powder disposal. This downtime reduced overall productivity.

With the dual-container system, tube one automatically transfers its contents to tube two once it reaches full capacity. This mechanism ensures continuous production while tube one is being emptied, eliminating scheduled downtime. The recovered production time amounts to 30 minutes per week, equivalent to 1,800 seconds, enabling the manufacturing of approximately 300 additional units per week based on the 6-second cycle time.

Regarding product quality, the system addresses the 100 defective units reported in December 2024 that were caused by copper dust adhering to commutator segments. By enabling real-time monitoring of suction pressure, anomalies can be detected and corrected immediately, significantly reducing the number of defective products in subsequent production cycles.

The early warning system enhances preventive maintenance by providing clear and timely alerts. Both tube-level conditions and dust collector performance are visualized using LEDs and reinforced with audible alarms. These alerts support rapid operator response, allowing abnormal conditions to be addressed before they escalate into failures.

A maintenance counter is also incorporated to track the remaining lifespan of critical components such as filters and hoses. This counter indicates when replacements are due, enabling predictive and scheduled maintenance rather than reactive repair. By avoiding unexpected failures, the system helps ensure uninterrupted production.

Additionally, the mobile-accessible ThingsBoard dashboard enables operators and supervisors to monitor machine conditions remotely, further increasing visibility and improving decision-making.

Effect on Key Performance Indicators (KPI)

The deployment of the IoT-based early detection system at PT XYZ positively influences several key performance indicators:

- Quality Improvement** Real-time pressure monitoring and tube-level detection significantly reduce the incidence of resistance-related defects. Potential issues are detected before they impact product quality, ensuring that manufactured units remain within acceptable tolerance limits.
- Availability Enhancement** The elimination of weekly downtime improves machine availability and increases actual productive time.
- Performance Rate Increase** With fewer defects and reduced downtime, the overall production throughput is improved. This directly enhances the performance component of the OEE (Overall Equipment Effectiveness) metric.
- Reduced Rework and Scrap** Minimizing dust-related contamination helps prevent non-conforming products, reducing both scrap and rework costs.

Estimated Production Savings

Before system implementation:

- Machine downtime: 30 minutes/week $\times$ 4 weeks = 120 minutes/month
- Production rate: 6 seconds/unit $\rightarrow$ 10 units/minute
- Lost production:
120 minutes $\times$ 10 = 1,200 units/month
- Average selling price per unit: USD 3.20
- Total potential loss:
1,200 $\times$ USD 3.20 = USD 3,840 per month

After system implementation:

- Downtime eliminated due to dual-container system
- Defective products reduced by 100 units/month
- Savings from reduced defects:
100 $\times$ USD 3.20 = USD 320/month
- Total monthly savings:
USD 3,840 + USD 320 = USD 4,160

These results demonstrate a substantial financial benefit and justify system deployment.

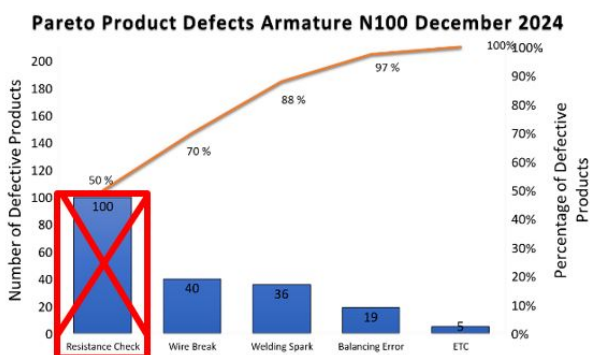


Fig. 26. Highest Pareto Chart Problem Solved

Conclusions

This study successfully developed and validated an IoT-based early fault detection system for the dust collector of a commutator cutting machine at PT XYZ. The system improves the reliability and efficiency of the production process by providing real-time monitoring of suction pressure and powder container levels. By integrating pressure and proximity sensors, visual and auditory indicators, automated valve control, and a remote monitoring dashboard, the system enables operators to detect anomalies early and perform timely preventive maintenance.

The implementation eliminates weekly downtime, reduces defective output, and increases overall production efficiency. Given its modular architecture, the system can be adapted to other industrial machinery susceptible to dust accumulation or pressure abnormalities, such as CNC machines, welding systems, and press equipment.

Future enhancements may include applying machine learning techniques for predictive maintenance, enabling the system to forecast failures based on historical sensor data. Such capabilities would further reduce operational disruptions and support more advanced automation strategies.

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