



Automated Multi-Size Radiator Cleaning System

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Abstract: :- This paper presents an Automated Multi-Size Radiator Cleaning System designed to adapt to various radiator dimensions. The system utilizes a servo-driven ball screw mechanism for precise movement, ensuring thorough cleaning without manual intervention. Advanced sensor-based adaptability allows dynamic path adjustments, optimizing efficiency for different radiator configurations. By integrating automation, this system enhances radiator performance, extends equipment lifespan, and reduces operational costs. Industrial cleaning automation improves operational efficiency, safety, and cost-effectiveness by reducing manual labor, minimizing downtime, and ensuring consistent, high-quality results. Radiators, essential for effective engine cooling, accumulate dust, oil, and debris, leading to performance degradation, overheating, and increased maintenance costs. Conventional cleaning techniques are inefficient, labor-intensive, and inconsistent, making automation a necessary solution.

Index Terms - radiator cleaning, automation, Servo-Driven Mechanism .

I. INTRODUCTION

Radiators are essential components used across various industries for efficient heat dissipation and thermal management. Commonly found in automobiles, power plants, manufacturing units, and heavy machinery, radiators play a vital role in maintaining optimal operating temperatures by transferring excess heat away from engines and equipment. Their effectiveness directly impacts system performance, safety, and longevity[7]. Radiator cleaning is a vital part of maintenance, as dust and oil particles accumulate between the fins, reducing cooling efficiency [12]. Regular cleaning using air or water jets helps restore airflow, but manual methods are time-consuming and inconsistent. Our system automates this process for faster and more effective maintenance in loco sheds. In this paper, we have focused on the implementation of an Automated Radiator Cleaning System specifically designed for use in loco sheds, where the radiators of diesel locomotives require regular maintenance. Due to the accumulation of dust, oil, and other particles, manual cleaning is labour-intensive, time-consuming, and inconsistent. Our machine addresses these challenges by automating the radiator cleaning process, ensuring efficiency, uniformity, and reduced manual effort ultimately improving the operational reliability of locomotives.

I. LITERATURE REVIEW

Various studies have explored advanced cleaning mechanisms for radiators and automated cleaning systems. A high-pressure air-assisted cleaning system was developed to remove dust and oil deposits efficiently from industrial radiators. While the system demonstrated improved cleaning performance, it lacked adaptability for different radiator sizes and configurations, making it unsuitable for large-scale locomotive applications. A hybrid ultrasonic and water jet cleaning system was introduced for automotive radiators, showing significant reductions in cleaning time and water consumption. However, the system required manual positioning, limiting its scalability and automation potential for locomotive radiators [5,10].

XY-axis automation has been widely researched in precision cleaning systems. An automated XY-axis gantry system was designed for cleaning solar panels using a servo-driven ball screw mechanism for precise linear motion. The study validated that servo-controlled XY-axis systems enhance cleaning consistency, supporting their integration into automated radiator cleaning solutions. Research on servo motors in automated conveyor systems highlighted their high torque control and energy efficiency. Findings confirmed that servo motors outperform stepper motors in maintaining smooth and adaptive motion, making them ideal for automated cleaning mechanisms that require precise positioning and dynamic adjustments [4,7].

The effectiveness of CNC-driven robotic cleaning systems was also analysed, focusing on precision motion control for variable surface cleaning applications. The study demonstrated that servo-integrated CNC systems improve speed accuracy and cleaning repeatability, reinforcing the necessity of programmable servo-driven motion in advanced cleaning automation [9].

II. WORKING

In Figure Number 1 The **Radiator Cleaning System** is powered by a 230V AC input, which is converted into 24V DC using a Switched Mode Power Supply (SMPS) rated at 24V/10A. This reliable and stabilized power supply ensures that all system components operate efficiently. During system initialization, the microprocessor performs a comprehensive status check on essential components such as the Micro PLC, servo motors, position sensors, ultrasonic sensors, and the solenoid valve flow regulator. A user-friendly display interface supports operator interactions, allowing the system to be turned on or off, indicators to be monitored, and the system to be reset with ease. To regulate voltage for sensitive electronics, the system uses a **Buck Converter**, a highly efficient DC-DC step-down converter. This device converts higher voltage levels like 12V or 24V down to 5V with minimal energy loss, unlike traditional linear regulators. The buck converter utilizes a combination of inductors, transistors, diodes, and capacitors to provide a stable and efficient power output. It is particularly beneficial for applications where power conservation is critical, such as in mobile devices and microcontroller-based systems. [8-9]

The core controller of the system is the **ESP32 microcontroller**, which manages all cleaning operations. It communicates with the operator through Bluetooth, enabling wireless control of system functions such as ON/OFF operation and reversing the cleaning mechanism. The ESP32 also handles the precise movement of servo motors, which direct the cleaning nozzle along the XY-axis. These movements are tailored to the dimensions of each radiator, with position sensors and limit switches providing real-time feedback to prevent over-travel and ensure accurate, safe operation. The radiator cleaning itself is carried out using a **high-pressure water jet**, initiated by activating a solenoid-controlled valve. [8,11]

This valve regulates the pressurized water that is sprayed onto the radiator fins, effectively removing dust, oil, and debris. The system dynamically adjusts the water pressure based on feedback from onboard sensors to ensure effective cleaning without damaging the radiator's delicate structure.[3]

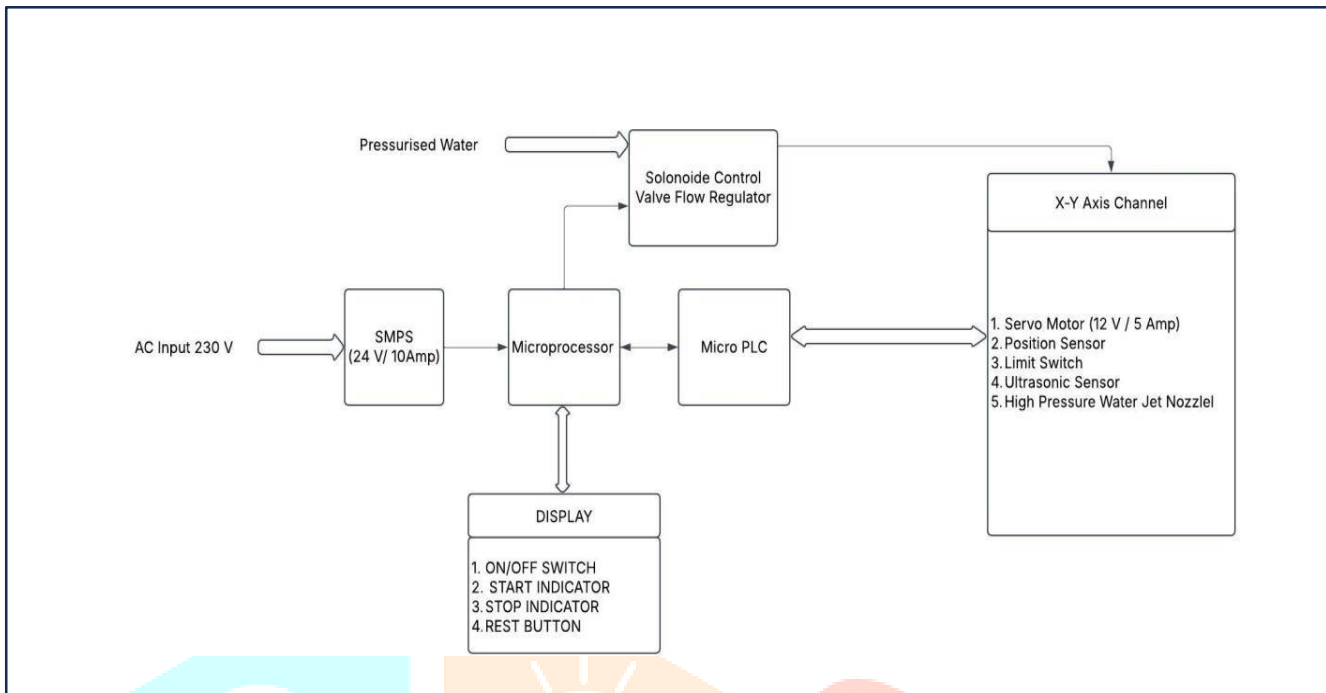


Fig .1. Automatic Radiator Cleaning Machine

In Figure Number 1 **Motion control** in the system is handled by servo motors powered by a 12V, 5A supply. These motors move the cleaning nozzle across the radiator's surface with precision. The ESP32 processes input from position sensors and limit switches to guide motor movements within a defined range, preventing any mechanical damage. The nozzle's motion is smooth and controlled, enabling it to reach all areas of the radiator and deliver a consistent, thorough cleaning. To enhance usability, the system is equipped with a **mobile monitoring interface** via Bluetooth. Operators can control power remotely, start or stop the cleaning process, and reset the system through a mobile application. Visual indicators display the system's current status, such as whether cleaning is active or completed. The ESP32 also logs key performance data and alerts operators in case of faults, improving maintenance scheduling and overall system reliability. [13]

IV. System Design

In the following Figure Number 2 the Automatic Radiator Cleaning System is designed to efficiently clean locomotive radiators using a motorized XY-axis mechanism and pressurized water jets. The system incorporates sensor-based automation to ensure precise movement and controlled cleaning. The automated radiator cleaning system is designed with a modular architecture, combining mechanical, electrical, and control subsystems for seamless operation. At its core, the system integrates a servo motor-driven XY-axis mechanism, which allows precise movement of the cleaning nozzle across the radiator surface. The nozzle delivers a high-pressure water jet controlled by a solenoid valve, efficiently dislodging dust, oil, and other contaminants. Limit switches provide positional feedback to avoid overtravel, ensuring safe operation.

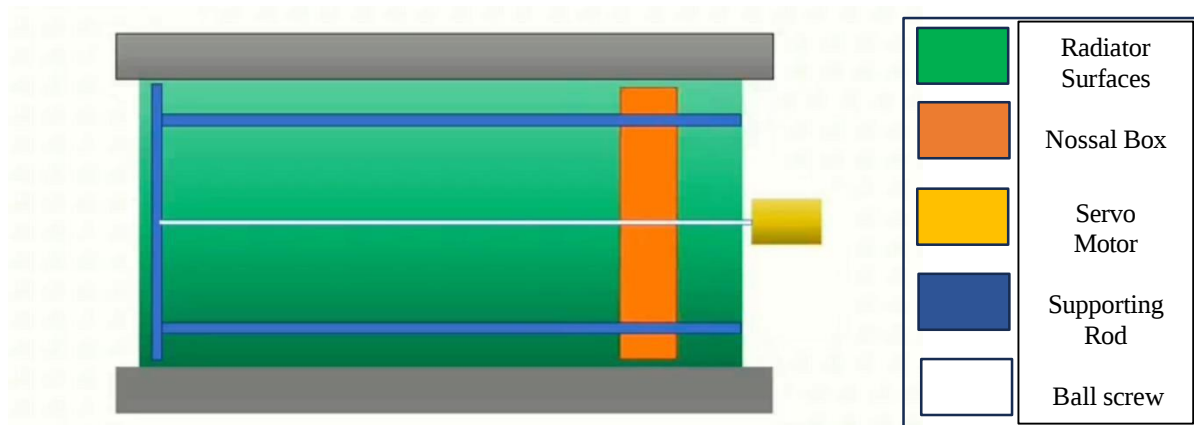


Fig.2. System Design of Radiator Cleaning System (TOP VIEW)

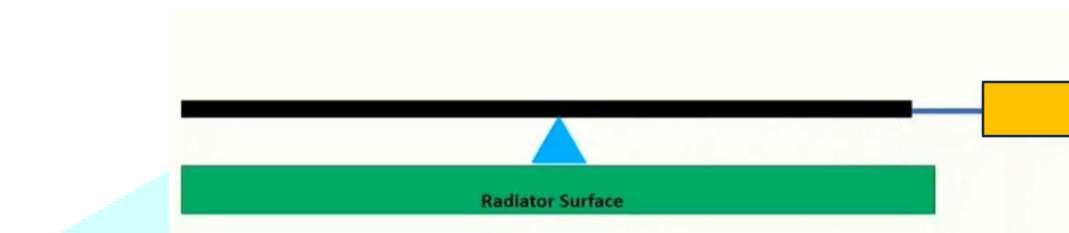


Fig.3. System Design of Radiator Cleaning System (SIDE VIEW)

From observation, here's a general breakdown:

- Green Section: Likely represents a cylinder or a moving platform (could be a cleaning nozzle or a mechanical carriage).
- Orange Sections: These could be supporting structures or guiding rails.
- Yellow Section: Might indicate a motor, actuator, or valve, as it appears to be a control point.
- Blue Sections: Likely linear guide rails or structural supports.
- Gray Sections: Appear to be end boundaries or fixed mounts.

V. SYSTEM HARDWARE

In Above figure Number 4 The power supply system of the automated radiator cleaning system ensures stable and reliable operation. It is powered by a 230V AC input at 50Hz, which is standard for industrial applications. This AC voltage is converted into 24V DC using a Switched Mode Power Supply (SMPS) rated at 24V/10A, providing power to the microprocessor, Micro PLC, and other electrical components. Additionally, a separate 12V, 5A power supply is dedicated to the servo motors, ensuring precise motion control during the cleaning process. This structured power supply setup enables smooth and efficient operation of all system components. The control and processing units are entirely managed by the ESP32 microcontroller, which acts as the central processing unit of the system. It executes system logic, manages control algorithms, and makes real-time decisions to optimize the cleaning process. The ESP32 also facilitates wireless communication via Bluetooth, allowing operators to remotely monitor and control the system through a mobile application. Furthermore, the ESP32 governs key components such as servo motors for nozzle movement and the solenoid valve for regulating water flow, ensuring fully automated and precise cleaning operations without the need for additional controllers.

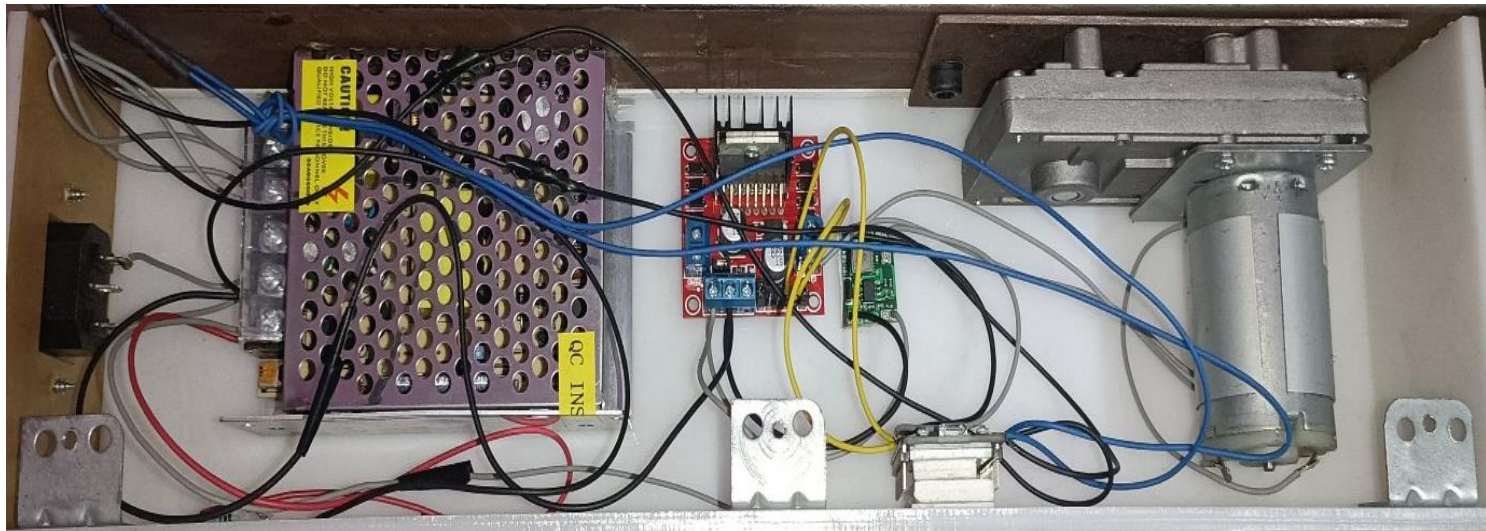


Fig.4. System Hardware



Fig .5. X-Y Axis Channel

In figure 5 The gearbox is a crucial mechanical component designed to increase torque while reducing rotational speed. It functions by utilizing a gear ratio, where a small input gear drives a larger output gear, effectively reducing speed while enhancing torque. This mechanism is essential for applications requiring high force output, such as lifting heavy loads or driving motors at controlled speeds. The ability to modify gear ratios allows for performance optimization, ensuring efficiency while preventing excessive power consumption. Gearboxes are widely used across industries, from automotive systems to automation machinery, where precise motion control and power management are critical. The high-pressure water jet cleaning mechanism is the core feature of the system, designed to effectively remove dust, oil, and debris from radiator fins. The cleaning process is initiated when a solenoid-controlled valve regulates the flow of pressurized water to the nozzle. The high-pressure nozzle directs a powerful water stream onto the radiator surface, ensuring thorough cleaning without structural damage. The system continuously adjusts water pressure based on real-time sensor feedback, optimizing cleaning efficiency while preventing excessive force on the radiator. This adaptive mechanism ensures safe and highly effective cleaning across various radiator configurations.

The limit switch feedback system plays a vital role in controlling the forward and reverse movement of the cleaning mechanism. Limit switches are strategically placed along the movement path to monitor the system's position. When the nozzle reaches its forward limit, the forward limit switch is activated, signalling the ESP32 to halt forward motion and, if necessary, switch to reverse. Similarly, when the system reaches the opposite end, the reverse limit switch stops the reverse movement and resets the direction. This feedback mechanism prevents over-travel, protects system components from damage, and ensures precise, controlled movement throughout the cleaning cycle.

The safety and emergency systems are designed to protect both the equipment and operators. Once a cleaning cycle is complete, the system automatically stops water flow and returns the cleaning nozzle to its home position. The ESP32 deactivates the servo motors, resetting the system for the next operation. In case of abnormal sensor readings or system malfunctions, the system includes an automatic emergency shutdown feature, which immediately halts all operations to prevent damage or injury. Safety sensors continuously monitor key parameters such as nozzle position and water pressure, ensuring that the system operates within safe limits at all times. These integrated safety measures enhance the reliability and long-term durability of the cleaning system.

VI. Advantages

1. Enhanced Cleaning Efficiency

- Ensure thorough and uniform cleaning with precise XY-axis navigation.
- Eliminates inconsistencies in manual cleaning.
- Programmable for various cleaning cycles based on radiator size and dirt level.

2. Adaptability to Different Radiator Sizes

- Intelligent XY-axis motion adjusts cleaning path dynamically.
- Compatible with multiple locomotive radiator models without manual adjustment.

3. Reduction in Labor & Maintenance Costs

- Minimizes manual labor, reducing workforce expenses.
- Faster cleaning process leads to reduced equipment downtime.
- Regular cleaning prevents long-term radiator damage, lowering maintenance costs.

4. Water & Energy Efficiency

- Solenoid control valve optimizes water usage, reducing wastage.

VII. APPLICATION

1. Locomotive Radiator Maintenance

- Efficient cleaning of railway locomotive radiators to prevent overheating.
- Reduces maintenance downtime in railway depots and workshops.

2. Industrial Heat Exchangers

- Used in power plants, oil refineries, and manufacturing industries to clean large-scale heat exchangers.
- Prevents efficiency loss due to dust, grease, and debris accumulation.

3. Automotive and Heavy Vehicle Radiators

- Suitable for trucks, buses, and heavy-duty construction equipment.
- Ensures optimal engine cooling, reducing fuel consumption and wear.

4. Aerospace and Aviation Industry

- It can be adapted for cleaning aircraft engine radiators and cooling systems.
- Enhance performance by removing dirt, oil residues, and contaminants.

5. Maritime and Naval Applications

- Cleaning of ship and submarine cooling systems to maintain efficiency in marine environments.
- Reduces corrosion and biofouling in seawater-cooled radiator

X. CONCLUSION

This paper presents the design and development of an automated radiator cleaning system tailored for locomotive maintenance applications. Through detailed analysis of existing methods and technologies, the study highlights the limitations of manual and semi-automated cleaning approaches, particularly in terms of labour intensity, inconsistency, and time inefficiency. By integrating an ESP32-based control unit, servo-driven motion, and a high-pressure water jet mechanism, the proposed system offers a reliable and scalable solution for maintaining radiator cleanliness. The use of position sensors, limit switches, and Bluetooth-based operation enhances the system's adaptability and user control. Experimental observations validate the system's ability to reduce maintenance time while improving cleaning precision and operator safety. Overall, this research contributes to the advancement of automated maintenance systems, offering insights into control architecture, system integration, and practical application in railway environments. Future studies may explore further automation using AI, predictive maintenance algorithms, and broader industrial **applicability**.

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