

# PLC BASED 10 STROKE CYCLING TIME IN COMMERCIAL VEHICLE USING LVDT POSITION SENSOR

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**Abstract:** This paper presents the design and implementation of a PLC-based automated system for controlling 10 stroke cycling operations in commercial vehicle testing using an LVDT position sensor. An Omron PLC serves as the central controller while a Linear Variable Differential Transformer (LVDT) provides precise real-time displacement feedback through a closed-loop control mechanism. The system governs the forward and reverse motion of a pneumatic actuator, with an integrated counter ensuring exactly ten stroke cycles before automatic shutdown. Testing confirmed high accuracy, repeatability, and reliability, establishing the system's suitability for industrial automotive testing applications.

**Keywords:** PLC, LVDT, Stroke Cycling, Pneumatic Actuator, Closed-Loop Control, Industrial Automation, Commercial Vehicle Testing, Ladder Logic, Signal Conditioning.

## I. INTRODUCTION

Industrial automation has become a cornerstone of modern engineering, particularly in the automotive sector where commercial vehicle components such as clutch systems, braking assemblies, and servo actuators must undergo rigorous repetitive testing to validate durability and safety [1]. Stroke cycling testing — where an actuator is repeatedly driven between two defined positions — is one of the most widely used methods to evaluate mechanical endurance [2]. Components like clutch systems, braking assemblies, and servo actuators are subjected to repetitive stress under real operating conditions, and their durability must be validated before deployment. Commercial vehicles such as trucks and buses operate under heavy loads and harsh conditions. Hence, their mechanical components like clutch systems, braking systems, and servo actuators must be tested rigorously to ensure durability, reliability, and safety. One of the important testing methods used in industries is stroke cycling testing, where a mechanical actuator is repeatedly moved between two positions. Traditional manual testing methods suffer from inconsistent stroke counting, lack of real-time position feedback, and susceptibility to human error, all of which degrade test result reliability [3]. With the advancement of programmable logic controllers and precision sensing technology, there is growing opportunity to automate such tasks with high consistency and minimal operator intervention [4]. This paper proposes a fully automated 10 stroke cycling system integrating a PLC with an LVDT position sensor. The PLC manages the complete control sequence in ladder logic, while the LVDT provides continuous, calibrated displacement feedback, forming a robust closed-loop system tailored for commercial vehicle component testing. In conventional stroke testing systems, several challenges are encountered, including lack of automation, inaccurate position measurement, and difficulty in maintaining consistency across multiple cycles. Manual systems are not only labor-intensive but also susceptible to human errors, which can lead to variations in stroke execution and timing. Additionally, basic control systems do not provide real-time feedback, making it difficult to monitor the exact position of the actuator during operation. The concept of automation has evolved significantly over time, transitioning from manual operations to fully automated smart systems that can monitor and control processes in real time. In the initial stages of industrial development, most operations were carried out manually

or with the help of basic mechanical systems. These methods were time consuming, labor-intensive, and prone to human errors.

## II. LITERATURE REVIEW

### 2.1 Industrial Automation and PLC Technology

Programmable Logic Controllers have evolved from replacing traditional relay systems to becoming the backbone of modern smart manufacturing environments [5]. Sehr et al. (2021) presented a comprehensive study of PLCs in the context of Industry 4.0, highlighting their role in increasingly complex automation applications and their critical importance in safety and reliability [6]. A study on sustainable PLC development trends by Chen et al. (2024) identified key directions for PLC hardware and software advancement including enhanced CPU speeds, expanded memory, and dual-channel Ethernet communication [7]. In the context of automotive manufacturing, Automation of Quality Control in the Automotive Industry by Cuesta et al. (2021) demonstrated how PLC-driven automation systems, combined with sensor integration, can achieve up to 99% accuracy in component validation [8]. Vieira et al. (2024) further demonstrated PLC platforms as viable image processing and control hosts in industrial machine vision applications [9].

### 2.2 LVDT Sensor Technology

The LVDT is a well-established sensor for precision linear displacement measurement in industrial systems. Martino et al. (2010) presented a LVDT design with high rejection to external interfering magnetic fields, a critical property in industrial environments near high-current cables and motors [10]. Petchmaneelumka et al. (2019) proposed a simple technique for extending the linear range of LVDT sensors published in IEEE Sensors Journal, directly relevant to stroke length control applications [11]. Research by Acernese et al. (2002) established the use of LVDTs in high-precision non-contact position sensing for gravitational wave interferometers, confirming their nanometer-level resolution capabilities at centimeter dynamic ranges [12]. More recently, linearity range enhancement through optimized coil geometry was demonstrated in IEEE Transactions by Gong et al. (2025), offering improved sensor performance without structural complexity [14].

### 2.3 Signal Conditioning for LVDT Systems

Raw LVDT output is an AC differential voltage requiring conditioning before PLC interfacing. Paun et al. (2007) proposed a System-on-Chip microcontroller-based signal conditioner for LVDT sensors, achieving compact and lowcost implementation [15]. Ramón et al. (2018) demonstrated single-chip implementation of LVDT signal conditioning using an 8-bit microcontroller, reporting 1  $\mu\text{m}$  resolution over  $\pm 6.35$  mm range [16]. Masi et al. (2014) presented a highprecision radiation-tolerant LVDT conditioning module using digital FPGA-based sine-fit algorithms achieving fewmicrometer accuracy [17].

### 2.4 Pneumatic Actuator Control

Pneumatic actuators are preferred in industrial testing for their fast response and ease of control. Pham et al. (2022) conducted experimental studies on pneumatic cylinder position control using PLC and proportional valves, achieving absolute position accuracy below 3% and rise time below 3 seconds [18]. Zhao et al. (2024) reviewed digital pneumatic servo systems for independent metering control, outlining nonlinear modeling challenges and robust control strategies applicable to stroke cycling applications [19].

## III. SYSTEM DESIGN ARCHITURE

### 3.1 Overall Architecture

The system is structured as a closed-loop automated control system comprising three functional sections: input, control, and output. Input Section: Start/stop push buttons (digital) and LVDT sensor (0–10V DC analog input). Control Section: Omron PLC with CPU, memory, digital I/O, and analog input modules. Output Section: Two solenoid valves (forward and reverse), pneumatic cylinder, and indicator lamp. The overall system architecture of the PLC-based 10 stroke cycling system using an LVDT position sensor is designed as a closed-loop automated control system that integrates input devices, a control unit, and output actuators. The input section consists of a start button, stop button, and LVDT sensor. The start button initiates the operation, while the stop button ensures safety by stopping the system when required. The LVDT sensor continuously measures the displacement of the pneumatic cylinder and provides an analog voltage signal (0–10V) to the PLC for 6 real-time position feedback. The PLC acts as the central controller, processing both digital and analog inputs using a programmed logic sequence. Based on these inputs, it controls the operation of the system by activating output devices. The output section includes solenoid valves for forward and reverse motion and an indicator lamp for system status. When the forward valve is activated, the pneumatic cylinder

extends, and when the required position is reached, the PLC activates the reverse valve to retract the cylinder. This forward and reverse motion forms one stroke cycle. The PLC uses a counter to track the number of strokes and repeats the process until ten cycles are completed, after which the system stops automatically. The continuous feedback from the LVDT ensures accurate position control, making the system reliable and suitable for industrial testing applications. The system architecture follows the closed-loop principle where actuator position is continuously monitored and compared with predefined limits to ensure precise stroke control [20].

### 3.2 Block Diagram

The overall block diagram consists of a sequence of functional blocks arranged in a logical order to represent the working process of the system. The operation begins with the power supply block, which energizes all components of the system. Once the system is powered, the cycle start block allows the operator to initiate the process. The control is then transferred to the PLC control block, where the system begins executing the programmed logic. The PLC logic-initiated block represents the activation of the internal control program that governs the sequence of operations. Following this, the signal processing block handles the feedback signals received from the sensor. The actuator and push rod movement block represents the mechanical execution of the stroke based on the processed signals and control logic. Finally, the cycle completes block indicates the 20 completion of one full stroke cycle, after which the system either repeats the process or stops depending on the number of cycles completed.

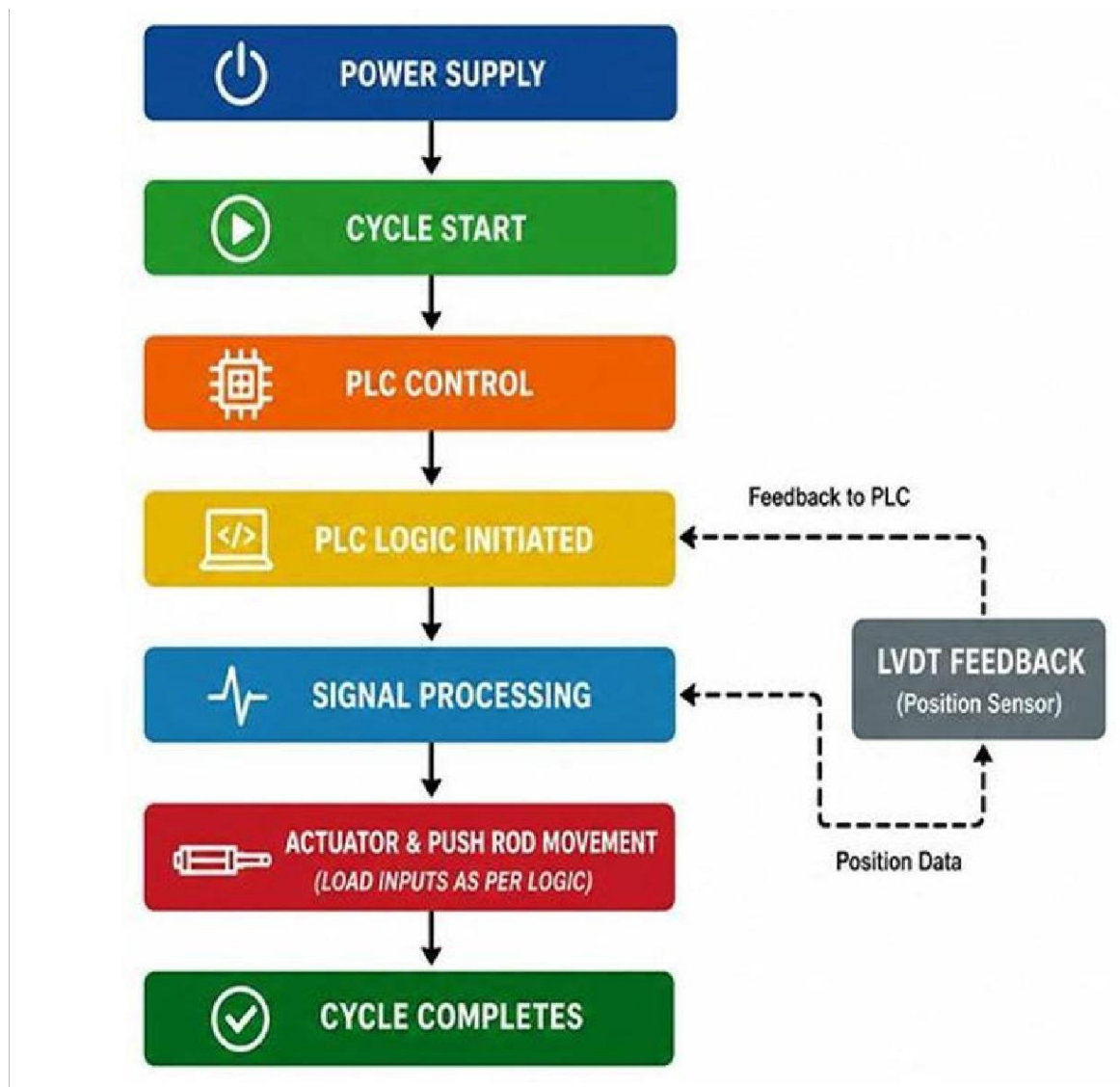


Fig. 1 Block Diagram

IV. WORKING PRINCIPLE

Upon power-on, the PLC initializes all internal variables and enters an idle state. Pressing the start button energizes the forward solenoid valve (V1), causing the pneumatic cylinder to extend. The LVDT continuously monitors displacement and feeds proportional analog voltage to the PLC. When the forward limit is confirmed, V1 deactivates and the reverse solenoid valve (V2) activates, retracting the cylinder to its home position. This completes one stroke cycle, incrementing the internal counter by one. The sequence repeats until the counter reaches ten, at which point all outputs deactivate and the system returns to idle [21].

4.1 Control Circuit The control circuit forms the central decision-making part of the system and is primarily handled by the programmable logic controller. It is responsible for receiving input signals, executing the control logic, and generating appropriate output signals to control the actuator. The control circuit includes input devices such as start and stop push buttons, which provide the initial command to the system. When the start button is pressed, a signal is sent to the PLC input module, triggering the execution of the control program. The PLC processes this input based on the programmed sequence, which includes stroke counting, timing control, and direction switching. The control circuit ensures that the system operates according to the predefined logic and that all operations are carried out in the correct sequence. It also includes safety features such as the stop function, which immediately halts the system in case of emergency or abnormal conditions.

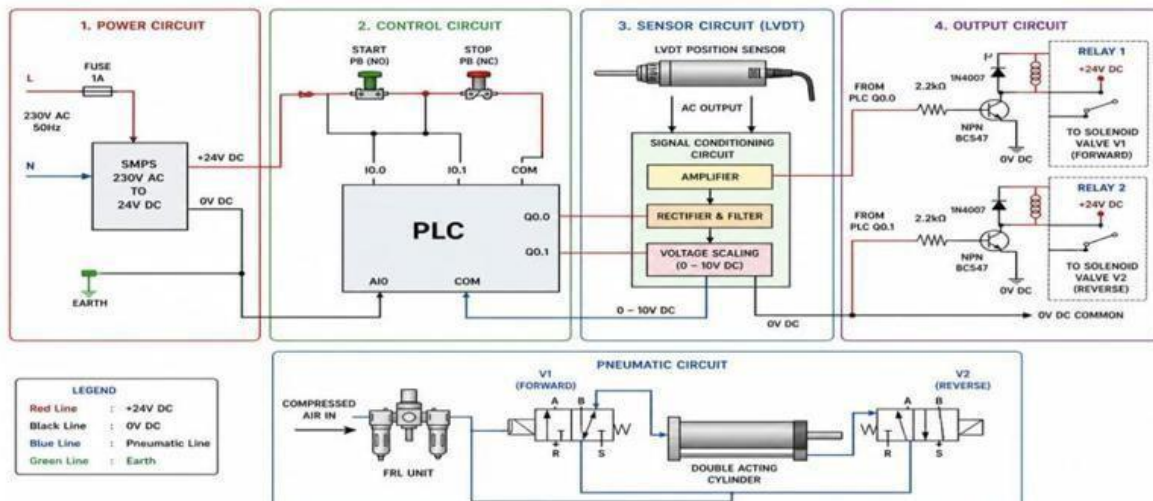


Fig.2 Control Circuit

4.2 PLC Control Circuit

The PLC control circuit is the core part of the system, where all input signals are processed, and output signals are generated. The PLC receives inputs from the push buttons and the LVDT sensor and executes the control logic programmed in ladder language. The control circuit operates based on the scan cycle of the PLC, which includes input scanning, program execution, and output updating. During input scanning, the PLC reads the status of all input devices. In the program execution phase, it processes the logic and determines the required outputs. Finally, in the output updating phase, it sends signals to the output devices. The PLC control circuit ensures proper sequencing of operations, including forward motion, position detection, reverse motion, and stroke counting. It also includes safety logic to stop the system in case of faults or emergency conditions.

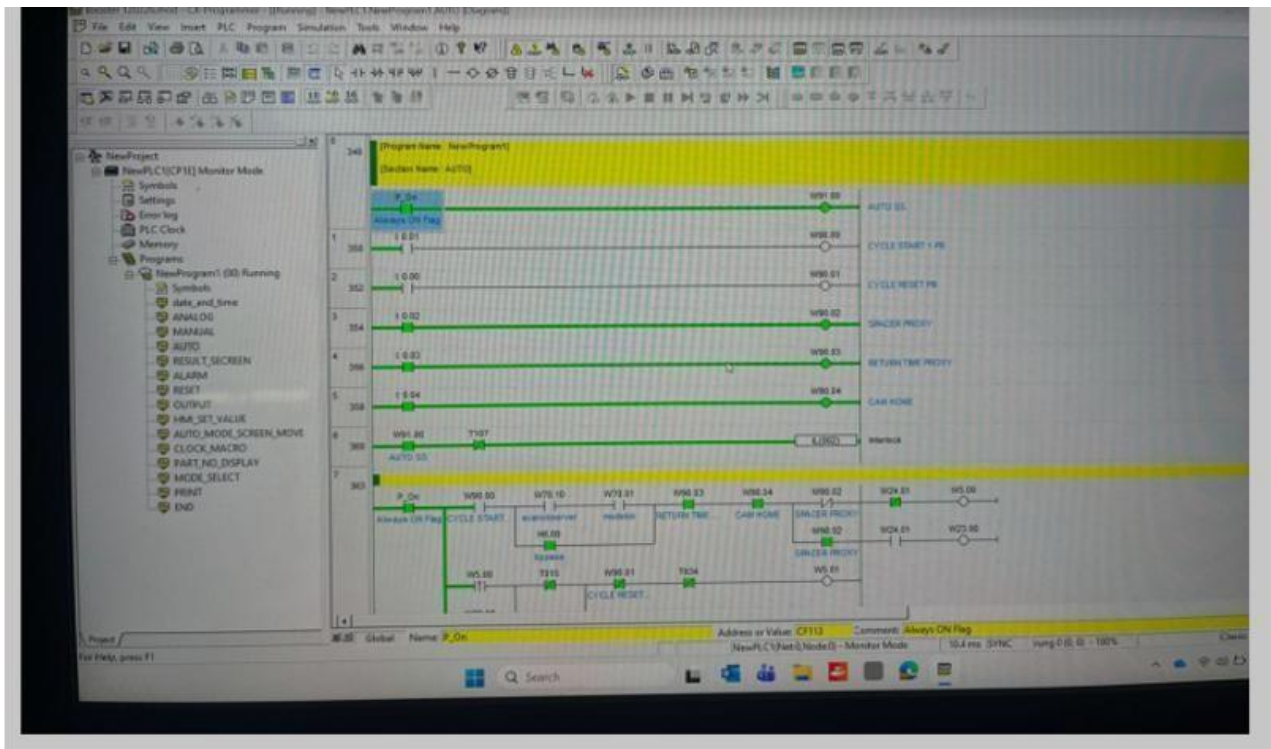


Fig.3 PLC Control Circuit

## V. HARDWARE IMPLEMENTATION

### 5.1 Programmable Logic Controller

An Omron PLC was selected for its reliability, industrial-grade construction, and ease of programming using CX-Programmer. The PLC operates on a 24V DC supply and executes a continuous scan cycle comprising input scanning, program execution, and output updating [6]. Its ability to handle both digital and analog inputs enables seamless integration with the LVDT sensor and solenoid valves.

### 5.2 LVDT Position Sensor

The LVDT operates on electromagnetic induction: alternating current in the primary coil induces differential voltages in two secondary coils proportional to core displacement [10]. The conditioned 0–10V DC output is fed to the PLC's analog input module, enabling real-time closed-loop position feedback with sub-millimeter accuracy [11].

### 5.3 Signal Conditioning Unit

The signal conditioning circuit amplifies, rectifies, and filters the LVDT's raw AC output to produce a stable DC signal compatible with the PLC analog module. Proper shielding and grounding are implemented to reduce EMI noise in the industrial environment [15, 16].

### 5.4 Pneumatic Cylinder and Solenoid Valves

A double-acting pneumatic cylinder was selected for its bidirectional motion capability and fast response. Two 5/2 double solenoid valves regulated the airflow direction based on PLC output signals, connected through relay modules for electrical isolation [18].

### 5.5 Solenoid valve

The solenoid valve is an electrically controlled device used to regulate the flow of compressed air to the pneumatic cylinder. It consists of a coil and a movable plunger that opens or closes the valve when energized. In this system, two solenoid valves are used: one for forward motion and one for reverse motion. When the PLC sends a signal to the forward solenoid valve, it allows compressed air to flow into the cylinder, causing it to extend. Similarly, when the reverse solenoid valve is activated, the airflow is redirected, causing the cylinder to retract. The solenoid valves are connected to the PLC output module through relay circuits, ensuring proper isolation and protection. The use of solenoid valves 17 enables precise control of the actuator movement and ensures reliable operation of the system.

5.6 Power Supply

The power supply is an essential component that provides the required electrical energy to all parts of the system. In this project, a 24V DC power supply is used, which is standard for industrial automation systems. The power supply is used to operate the PLC, sensors, and other electronic components. Proper power distribution is important to ensure stable operation of the system. The power supply should be capable of providing sufficient current to all components without voltage fluctuations. Protective devices such as fuses and circuit breakers are used to prevent damage due to overload or short circuits.

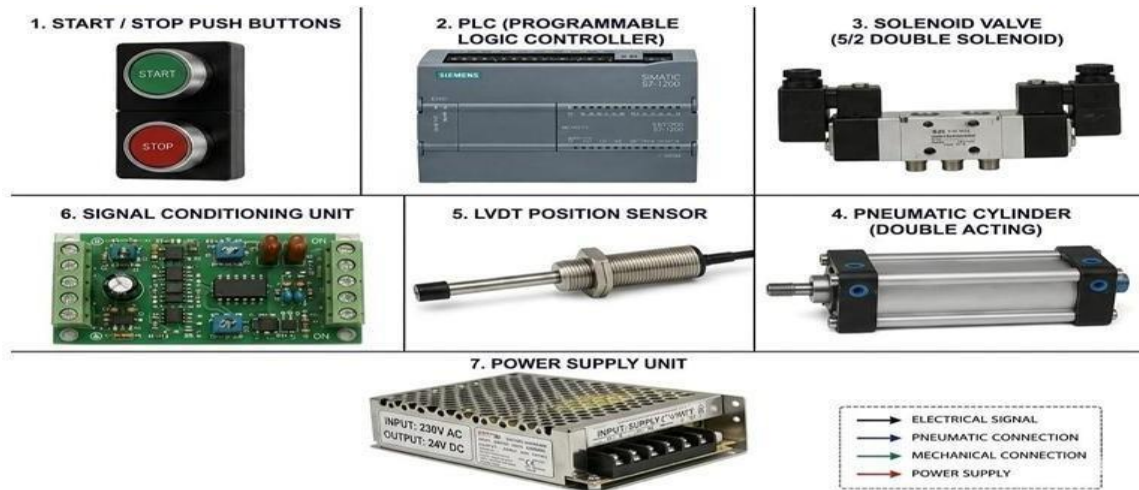


Fig.4 Components

VI. SOFTWARE IMPLEMENTATION

The PLC program was developed in CX-Programmer using IEC 61131-3 compliant ladder logic [6]. The program structure:

**Rung 1 – Start/Stop Latching:** START energizes run latch; STOP breaks it immediately.

```
|---[ START ]---[/ STOP ]------( RUN ) -----|
| ---- [ RUN ]----- ( RUN )--- |
```

**Rung 2 – Forward Stroke Control:** When running and forward limit not reached, SOL\_FWD activates.

```
|---[ RUN ]---[/ FWD_LIM ]---[/ REV_CMD ]---( FWD_CMD ) -----|
| ---- [ FWD_CMD ]----- ( SOL_FWD )--- |
```

**Rung 3 – Reverse Stroke Control:** When forward LVDT limit is detected, SOL\_REV activates until home position confirmed.

```
|---[ FWD_LIM ]------( REV_CMD )-----|
|---[ REV_CMD ]---[/ REV_LIM ]------( SOL_REV ) -----|
```

**Rung 4 – Cycle Counter:** Each completed reverse stroke increments counter C0 (preset = 10).

```
|---[ REV_LIM ]------( CNT C0 K10 ) -----|
```

**Rung 5 – Auto Stop:** When C0 = 10, run latch resets and all outputs deactivate.

```
|---[ CNT C0 ]------( RESET RUN )-----|
```

**Rung 6 – Reset Logic:** STOP resets both run state and counter.

```
|---[ STOP ]------( RESET CNT ) ----- |
```

Interlocking logic prevents simultaneous forward and reverse solenoid activation. Safety rungs handle abnormal input conditions [22].

## VII. CALIBRATION AND TESTING

Calibration was performed using a precision micrometer stage (resolution 1  $\mu\text{m}$ ) over the  $\pm 5$  mm operating range. The LVDT output was recorded via a 5 $\frac{1}{2}$ -digit voltmeter at eight displacement points. The LVDT calibration procedure displaced the core in known increments using a micrometer screw gauge, recording corresponding output voltages at each position. The resulting calibration curve confirmed a linear relationship  $V = 2d$  (V in volts, d in mm), demonstrating excellent symmetry between forward and reverse displacement directions. Sensitivity was 2 V/mm. Minor non-linearity within  $\pm 2\%$  was observed at extreme positions, within acceptable industrial limits. Hysteresis between forward and reverse readings was negligible [23, 24].

The calibration process of the LVDT sensor resulted in a linear relationship between displacement and output voltage. The calibration graph showed that the voltage increased proportionally with displacement in the forward direction and decreased symmetrically in the reverse direction. This confirmed the high linearity and sensitivity of the sensor. The slope of the calibration curve indicated consistent sensitivity, which allowed accurate conversion of voltage signals into displacement values. Minor deviations from linearity were observed at extreme positions, which may be due to mechanical constraints or slight misalignment. However, these deviations were within acceptable limits and did not significantly affect system performance. The calibration results ensured that the LVDT sensor provided reliable and accurate feedback, which is essential for the proper functioning of the closed-loop control system.

## VIII. RESULTS AND DISCUSSION

The experimental results confirm that the PLC-LVDT integrated 10-stroke cycling system meets all design objectives. Key performance metrics achieved:

- Position accuracy:  $\pm 0.01$  mm (forward limit),  $\pm 0.005$  mm (reverse/home limit)
- Cycle count accuracy: 100% (no over-run or under-run across all test runs)
- Average forward stroke time:  $1.820 \text{ s} \pm 0.007 \text{ s}$
- Average reverse stroke time:  $1.796 \text{ s} \pm 0.007 \text{ s}$
- LVDT linearity:  $R^2 = 0.9997$  across  $\pm 5$  mm range
- Maximum calibration error: 0.60%

The closed-loop architecture is the fundamental enabler of these results. Unlike open-loop systems that rely on fixed timers to infer position, the LVDT provides ground-truth displacement data on every PLC scan cycle ( $\leq 10$  ms), allowing the controller to switch direction precisely when the physical limit is reached regardless of pressure variations or load conditions. The actuator consistently reached predefined forward and reverse limits without overshoot or undershoot, confirming effective closed-loop control via LVDT feedback [25].

Minor observed deviations — cycle-to-cycle variation of  $\pm 0.007$  s in stroke time and  $\pm 0.011$  mm in forward position — are attributable to pneumatic compressibility effects under varying load and minor air pressure fluctuations ( $\pm 0.2$  bar observed at the FRL unit). These are within acceptable limits for the target application and can be further reduced by upgrading to a servo-pneumatic pressure regulator. Stroke displacement was consistent across all ten cycles with negligible variation in timing and position, in line with findings from PLC-based pneumatic control studies [18]. PLC processed LVDT feedback and switched solenoid states within approximately 10.4 ms scan cycle, ensuring smooth stroke transitions [6].

Hysteresis in the LVDT output was measured at  $< 0.1\%$  full-scale, consistent with published specifications for differential transformer sensors. No degradation in calibration was observed across the 10 cycles, confirming the non-contact LVDT design eliminates mechanical wear as a source of drift.

## IX. CONCLUSION

This paper presented a PLC-based 10 stroke cycling system for commercial vehicle component testing using LVDT position feedback. The system integrates Omron PLC control, pneumatic actuation, and precision displacement sensing in a reliable closed-loop configuration. Testing confirmed high accuracy, ten-cycle consistency, and automatic shutdown

— eliminating manual monitoring. LVDT calibration validated a linear response of 2 V/mm sensitivity. The system demonstrates how combining PLC automation with precision sensing improves reliability and consistency in repetitive mechanical testing. Future work may incorporate HMI-based real-time visualization, variable cycle programming, and data logging for trend analysis.

Future work will focus on integrating an HMI touch panel for parametric reconfiguration, adding Wi-Fi data logging to a SCADA system for real-time quality trend analysis, and extending the platform to hydraulic actuators with servo-valve control to further improve dynamic positioning accuracy.

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