Design and Development of a Fully Automated Oil Pump Testing System for Industrial Applications

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Abstract— **The development of a fully automated oil pump testing system addresses the limitations of conventional manual testing methods, which are often time-consuming, error-prone, and unsafe. This project presents an advanced test setup that integrates a Programmable Logic Controller (PLC) and LabVIEW-based data acquisition system with precision sensors to measure key parameters such as flow, pressure, torque, temperature, and speed. The system automates valve control, data logging, and report generation, enhancing the accuracy and repeatability of oil pump performance evaluation. Real-time data acquisition and automated test sequencing significantly reduce human intervention while improving operational safety and reliability of the test results. The proposed solution demonstrates a modernized testing approach that ensures standard compliance and alignment with current industrial automation trends.**

Keywords— Oil Pump Testing, Programmable Logic Controller (PLC), LabVIEW, Industrial Automation, Performance Evaluation.

I. INTRODUCTION

Oil pumps are essential components in a wide range of industrial and automotive applications, and their performance directly influences the reliability and efficiency of the overall system. Traditionally, oil pump testing has relied on manual operations involving valve adjustments, data recording, and report preparation. These procedures are labor-intensive, time-consuming, and prone to human error, which can affect safety and lead to inconsistent test results.

To overcome these limitations, this work focuses on the design and development of a fully automated oil pump testing system. The proposed setup integrates Programmable Logic Controller (PLC) technology for control with a LabVIEW-based system for real-time monitoring and data acquisition. A set of high-accuracy sensors is used to measure key parameters such as flow, pressure, torque, temperature, and speed, enabling comprehensive evaluation of pump performance under different operating conditions.

In many existing testing systems, control and data acquisition are often implemented as separate or loosely connected subsystems, which can limit synchronization and reduce overall system efficiency. In contrast, the present system adopts an integrated approach in which both functionalities operate within a unified framework. This enables coordinated interaction between field instrumentation and supervisory control, ensuring stable and consistent operation during testing.

The developed test bench is capable of performing multiple testing modes, including endurance, cavitation, aeration, cyclic, and pulsation testing within a single setup. This reduces the need for multiple standalone arrangements and improves overall testing flexibility. In addition, automated test sequencing, valve control, and report generation help standardize the testing procedure, reduce manual intervention, and improve repeatability and traceability.

Unlike conventional testing systems where control and data acquisition are implemented as separate or loosely connected subsystems, the proposed system integrates PLC-based control with SCADA-based monitoring within a unified framework. This integration ensures synchronized operation, improved system coordination, and enhanced reliability, thereby addressing limitations of existing test benches in terms of flexibility, consistency, and operational efficiency. Aligned with Industry 4.0 principles, the system demonstrates how the integration of automation, instrumentation, and data acquisition can transform conventional testing into a more efficient and data-driven process. The overall design provides a practical and scalable solution that can be readily adopted in industrial environments and further extended for advanced monitoring and predictive maintenance applications.

II. LITERATURE REVIEW

The development of automated test benches for hydraulic and oil pump systems has gained significant attention due to the increasing demand for accuracy, reliability, and efficiency in industrial testing. Existing research primarily focuses on pump performance evaluation, failure analysis, system design, and automation techniques.

A major portion of literature emphasizes pump performance characteristics and influencing parameters. Sakran et al. [3] reviewed the effect of blade number on centrifugal pump performance, highlighting its influence on efficiency and flow behaviour. Similarly, Stawiński et al. [8] investigated the impact of hydraulic oil temperature on pump performance, demonstrating that temperature variations significantly affect efficiency and operational stability. Wang et al. [22] further contributed by improving pump setpoint selection using calibrated hydraulic models, enabling optimized performance under varying operating conditions. Yang et al. [13] analysed energy characteristics of large pump systems, providing insights into energy efficiency and operational behaviour.

Another critical area of research is failure analysis and reliability assessment of pumps. Lee et al. [2] studied failure causes of oil pumps under different operating conditions, identifying key factors such as wear, lubrication issues, and load variations. Qi et al. [20] conducted accelerated degradation testing to evaluate pump reliability and predict failure trends. Abhyankar et al. [4] developed an endurance testing methodology for engine oil pumps, focusing on fatigue and durability under continuous operation. These studies highlight the importance of systematic testing frameworks for ensuring pump reliability.

Significant work has also been carried out in the design and development of hydraulic test benches. Pan et al. [5] designed a performance testing system for high-pressure gear pumps, while Elshorbagy et al. [7] developed a multifunctional hydraulic test stand capable of testing multiple hydraulic components. Xu et al. [10] proposed an automatic hydraulic pump test system based on a client–server architecture, improving system scalability and data handling. Li et al. [14] introduced a fully automated pump performance test system, emphasizing precision and reduced human intervention. Similarly, Rybak et al. [15] validated a test stand for hydraulic cylinders, demonstrating the importance of experimental verification in test setups.

Recent studies have focused on simulation-based analysis and hybrid testing approaches. Schumacher et al. [6] used simulation techniques to predict cold-start behavior of gerotor pumps, enabling better design optimization. Kamarudin et al. [16] combined simulation and experimental methods to study hydraulic pump characteristics, improving accuracy in performance prediction. These approaches reduce dependency on physical trials and enhance design efficiency.

In terms of efficiency improvement and optimization, Rybak et al. [11] worked on improving the drive efficiency of hydraulic test benches, while Gaugel and Epple [12] applied data-driven multi-objective optimization to enhance end-of-line test cycles. These studies demonstrate the growing role of optimization techniques in improving testing systems.

Automation plays a crucial role in modern testing systems, and two dominant approaches are observed in literature: PLC-based control systems and LabVIEW-based data acquisition systems. Yürekli and Dogan [9] developed a PLC-based hydraulic test unit for diagnostics and testing, emphasizing robust and reliable control. Quintero et al. [1] implemented a LabVIEW-based data acquisition system integrated with Arduino, enabling real-time monitoring of pump parameters. Xu et al. [10] and Li et al. [14] also incorporated automation frameworks to improve system performance and data management.

An emerging trend is the integration of PLC and LabVIEW for advanced industrial automation. Padmanabhan et al. [17] demonstrated IoT-based automation using PLC and LabVIEW, while Padmanabhan et al. [18] further explored their convergence for smart industrial systems. These integrated architectures combine the deterministic control capabilities of PLCs with the powerful visualization and data acquisition features of LabVIEW.

The concept of Industry 4.0 and smart monitoring has further enhanced pump testing systems. Ramzey et al. [19] developed IIoT-based remote monitoring systems for oil and pump industries, enabling real-time data access and predictive maintenance. Rahman et al. [21] reviewed machine-learning-driven automation in manufacturing, highlighting the future scope of intelligent testing systems incorporating AI and data analytics.

From the reviewed literature, it is evident that most existing systems focus on either performance analysis, failure diagnostics, or standalone automation techniques. Although several studies address PLC-based control or LabVIEW-based monitoring independently, limited work has been reported on their integrated implementation in a unified oil pump testing framework. Additionally, many systems lack the capability to perform multiple testing modes within a single setup, such as endurance, cavitation, and cyclic testing.

Therefore, there is a clear need for a fully integrated, automated, and multi-functional oil pump testing system that combines PLC-based control, LabVIEW-based data acquisition, and modern industrial automation principles. The present work addresses this gap by developing a comprehensive PLC–SCADA-based oil pump testing system ensures accurate measurement, real-time monitoring, improved repeatability, and suitability for industrial applications.

III.METHODOLOGY

A. *System Design and Architecture*

The system design begins with the development of a detailed Piping and Instrumentation Diagram (P&ID), which defines the process flow, measurement points, and control interfaces required for oil pump performance evaluation.

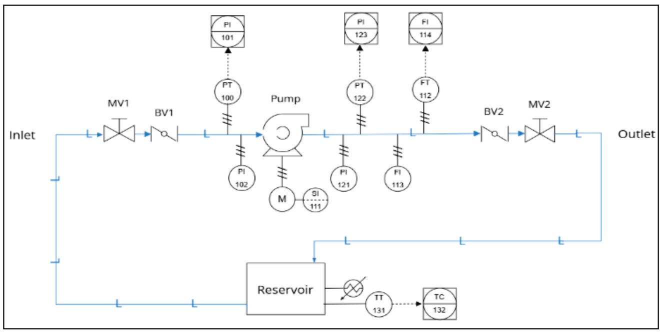


Fig. 1. Piping and Instrumentation Diagram (P&ID) of the automated oil pump test bench.

Figure 1 shows the interconnection of the oil pump, pressure transmitters, flow meter, control valves, and data acquisition hardware. The diagram defines all required measurement points and control interfaces used for automated testing and performance analysis.

TABLE I.
AUTOMATION AND INSTRUMENTATION COMPONENTS

Sr. No.	Component	Make / Model
1	Pressure Transmitter – Suction	Baumer CTX323B76.0
2	Pressure Transmitter – Discharge	Baumer CTX323B24.0
3	Analog Pressure Gauge	WIKA
4	Flow Meter	Bronkhorst D-6361A
5	Temperature Measurement (RTD + Tx)	Radix TX1HM
6	RPM Sensor	Omron 409-S RPM-1-1
7	Energy Meter	Rish EM1340
8	PLC	Delta SA2
9	VFD (Motor Drive)	Yaskawa Varispeed F7
10	Motorized Butterfly Valve	Apollo Valves
11	Reservoir & Process Piping	Fabricated Assembly
12	Reporting Software	LabVIEW-based

TABLE II.
ELECTRICAL, PANEL, AND ANCILLARY COMPONRNTS

Sr. No.	Component	Make / Model
1	Switchgear & Protection	MCB/MCCB/contactor set; panel protection
2	Solid State Relay (SSR)	16 A; heat-sink mounted
3	SMPS	24 V DC, 6.2 A
4	Emergency Stop Switch	Latching mushroom; panel mount
5	Tower Lamp	3-tier with 24 V buzzer
6	Control Panel Enclosure	1700 × 600 × 600 mm; wired assembly
7	Cabling	LAN (PLC–PC, 5 m) + control/power wiring
8	Isolation Transformer	750 VA; Pri 0–440 V / Sec 0–230 V
9	FRL Unit	Port size ½″ (air line service)

B. *Instrumentation and I/O Configuration*

A comprehensive I/O configuration was developed to interface all field sensors and control elements with the PLC-based automation system. Analog channels were utilized for acquiring critical process parameters such as pressure and flow, while digital signals facilitated command execution, protection interlocks, and status feedback. This structured allocation of I/O ensured seamless integration of field instrumentation with the control logic for efficient and automated pump performance testing.

TABLE III.
PLC I/O CONFIGURATION

I/O Type	Quantity	Description
Analog Input (AI)	3	Suction Pressure, Delivery Pressure, Flow Measurement
Analog Output (AO)	1	VFD Speed Reference Control
Digital Input (DI)	4	Start, Stop, Emergency Stop, VFD Fault Status
Digital Output (DO)	4	VFD Run Command, Fault Reset, Tower Lamp Indications (R/Y/G)

The wiring architecture was designed in accordance with standard industrial instrumentation and control panel practices. Shielded cables were employed for analog signal lines to minimize electrical noise, while power and control wiring were routed separately to prevent interference. Single-point grounding, systematic ferrule-based wire labeling, and terminal-based field interfacing were adopted to ensure safe operation, ease of troubleshooting, and long-term reliability.

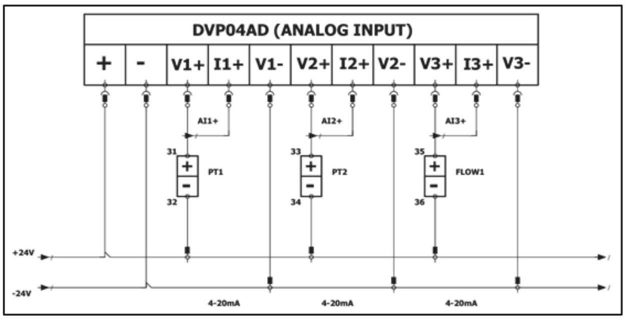


Fig. 2(a). Analog input wiring diagram.

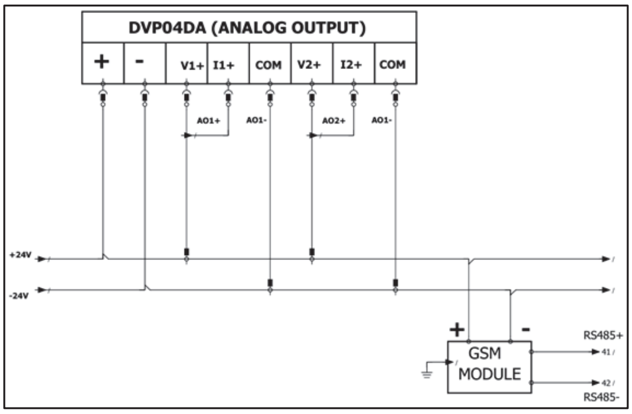


Fig. 2(b). Analog output wiring diagram.

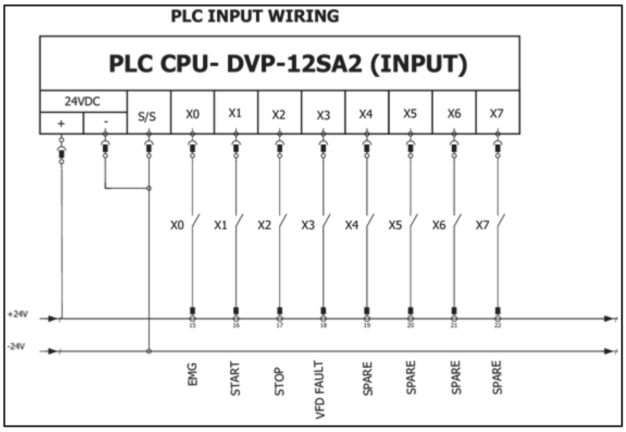


Fig. 2(c). Digital input wiring diagram.

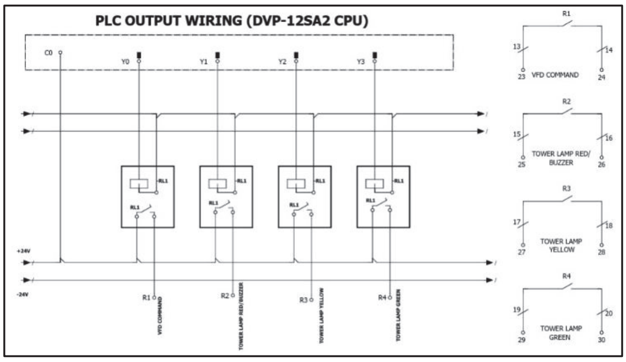


Fig. 2(d). Digital output wiring diagram.

The complete PLC wiring configuration is illustrated in Fig. 2(a)–2(b), presenting the digital input, digital output, analog input, and analog output interfacing used in the system.

C. Theoretical Background

The performance of an oil pump is governed by the relationship between flow rate, pressure, and operating conditions. Typically, the flow rate increases with pump speed and decreases with higher delivery pressure.

The hydraulic power developed by the pump is given by:

$$P = \rho * g * Q * H \tag{1}$$

where ρ represents the fluid density, g is gravitational acceleration, Q is the flow rate, and H is the head.

These relations help in analyzing pump behavior under varying conditions and are used to compare theoretical and experimental results obtained from the automated testing system.

D. Control System Implementation

The control system for the oil pump test bench was implemented using a Programmable Logic Controller (PLC) to execute the automated test sequence, enforce safety conditions, and manage data flow during operation. The PLC was programmed using sequential logic with defined operational states: Initialization, Pre-Test Checks, Test Execution, Data Logging, and Safe Shutdown.

Each operational state performs specific control tasks such as valve actuation, motor start/stop commands, and alarm handling. Ladder logic routines were organized into modular networks for interlocks, analog input processing, and alarm management. The overall ladder logic implementation is illustrated in Fig. 3.

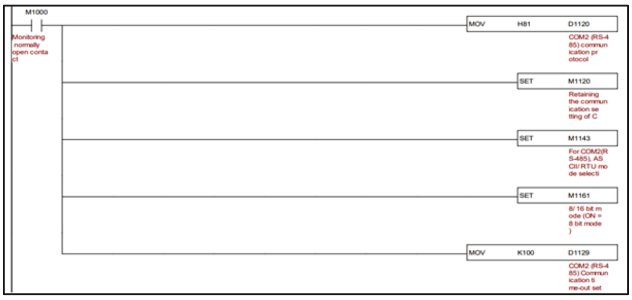


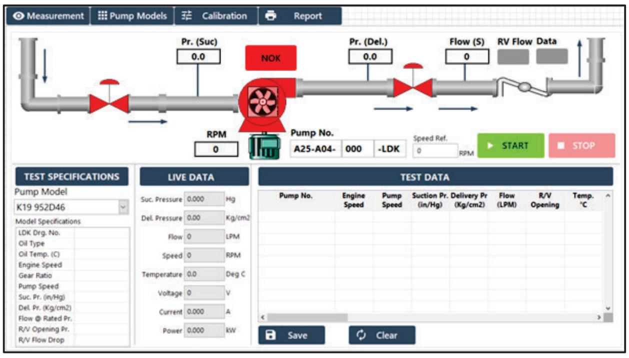
Fig. 3. Control logic in PLC ladder.

Figure 3 presents the structured PLC ladder logic used for automated test sequencing, safety interlocks, and coordinated control of system components. The logic ensures reliable execution of test operations while maintaining protection and fault-handling mechanisms.

E. SCADA and Data Acquisition

The Supervisory Control and Data Acquisition (SCADA) interface, developed using LabVIEW, provides real-time visualization, data trending, and automated report generation for the oil pump testing system. Key process parameters such as flow, pressure, torque, temperature, and speed are displayed on a unified monitoring screen along with test status indicators and alarm notifications.

The SCADA platform continuously logs time-stamped data for each parameter, enabling traceable performance evaluation and generation of standardized test reports. User-defined test configurations, including flow and pressure setpoints and test duration, can be selected directly through the SCADA interface prior to execution. The developed SCADA interface is illustrated in Fig. 4.



Pr. (Suc) 0.0
Pr. (Del.) 0.0
Flow (S) 0
RPM 0
Pump No. A25-A04- 000 -LDK
Speed Ref. 0 RPM

Pump Model
K19 952D46
Model Specifications
LDK Drg. No.
Oil Type
Oil Temp. (C)
Engine Speed
Gear Ratio
Pump Speed
Suc. Pr. (in/Hg)
Del. Pr. (Kg/cm2)
Flow @ Rated Pr.
R/V Opening Pr.
R/V Flow Drop

Suc. Pressure 0.000 Hg
Del. Pressure 0.00 Kg/cm2
Flow 0 LPM
Speed 0 RPM
Temperature 0.0 Deg C
Voltage 0 V
Current 0.000 A
Power 0.000 kW

Pump No.	Engine Speed	Pump Speed	Suction Pr. (in/Hg)	Delivery Pr (Kg/cm2)	Flow (LPM)	R/V Opening	Temp. °C

Fig. 4. LabVIEW-based SCADA interface for real-time monitoring and data logging.

Figure 4 presents the LabVIEW-based SCADA interface used for real-time monitoring, data acquisition, and automated report generation. The interface enables visualization of critical process variables, alarm management, and configuration of test parameters in a user-friendly environment.

F. Testing Procedure

Prior to executing any test run, preliminary checks were performed to ensure system readiness and operational integrity. These checks included leak inspection, zero calibration of sensors, and verification of communication links between the PLC and SCADA modules.

All sensors were calibrated prior to testing using standard reference methods. Measurement uncertainty was minimized through proper sensor selection, shielding, and stable operating conditions. Minor deviations observed across test runs fall within acceptable industrial tolerance limits.

After successful validation of all initial conditions, the automated test routine was executed to evaluate pump performance under various operating modes. During the test sequence, the PLC controlled pumps, valves, and actuators based on predefined logic, while the SCADA system simultaneously acquired, displayed, and stored real-time data.

The automated procedure enabled consistent and repeatable testing with minimal human intervention, ensuring operational safety and accurate measurement of performance parameters.

IV. Documentation and Integration

Complete technical documentation was prepared, covering system design, instrumentation layout, I/O mapping, wiring diagrams, PLC control flowcharts, SCADA screens, and system photographs. All mechanical, electrical, and control modules were integrated to form a fully automated oil pump testing setup. The installed plant, consisting of the test bench, control station, and instrumentation network, is illustrated in Fig. 5.

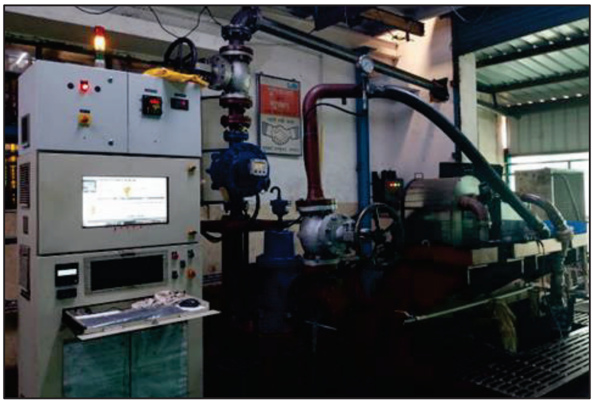


Fig.5. Automated oil pump test bench setup.

Figure 5 shows the fully assembled automated oil pump test bench, including the mechanical structure, instrumentation network, control station, and interconnecting process piping used for pump performance evaluation.

A dedicated control panel was fabricated to house the PLC, power supply units, relays, protection devices, and interfacing terminals to ensure safe and reliable system operation. Standard industrial wiring practices such as cable segregation, ferrule-based labeling, shielding for analog signal loops, and DIN-rail mounting were followed to meet industrial standards. The internal layout of the assembled control panel is shown in Fig. 6.

Fig. 6. Control panel wiring and PLC integration

Figure 6 illustrates the internal arrangement of the control panel, highlighting the integration of the PLC, power supplies, protection devices, relays, and terminal connections implemented in accordance with standard industrial control panel design practices.

All system modules including sensing, control, data acquisition, actuation, safety, and reporting were successfully integrated into a cohesive automated platform aligned with

Industry 4.0 principles for smart and data-driven industrial testing.

RESULT AND DISCUSSION

The developed automated oil pump testing system was evaluated under varying operating conditions to assess pump performance, system stability, and measurement reliability. The integrated PLC–SCADA framework enabled continuous monitoring and logging of all key parameters throughout the testing process. The recorded experimental values for multiple test samples are presented in Table IV.

The eight samples presented in Table IV correspond to eight independent test runs conducted on the same oil pump under varying operating conditions (different pressure and flow setpoints). These repeated trials were performed to evaluate system repeatability and performance consistency.

TABLE IV.

SAMPLE TEST RESULTS OF OIL PUMP PERFORMANCE

Sr. No.	Sample ID	Suction Pressure (in/Hg)	Delivery Pressure (kg/cm^2)	Flow (LPM)	Temperature (°C)
1	Sample 1	0.954	4.28	430	50.9
2	Sample 2	0.951	4.25	403	50.9
3	Sample 3	0.970	1.32	615	50.7
4	Sample 4	0.952	4.26	435	48.5
5	Sample 5	0.958	4.06	473	50.5
6	Sample 6	0.964	4.15	451	54.7
7	Sample 7	0.958	3.98	451	48.3
8	Sample 8	0.956	3.36	455	51.6

The relationship between flow rate and suction pressure, as well as delivery pressure, is illustrated in Fig. 7.1. and Fig. 7.2., respectively.

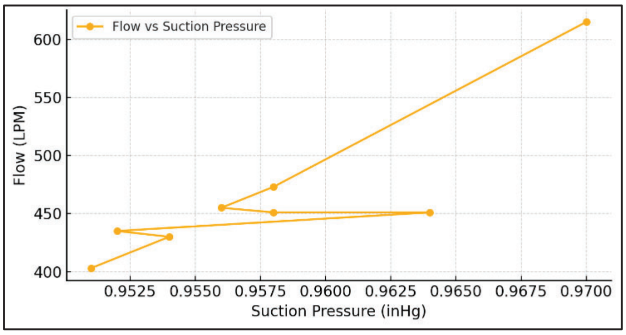


Fig. 7(a). Comparison of Suction Pressure with Flow

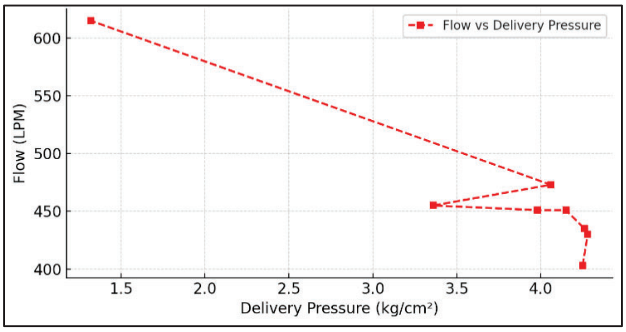


Fig. 7(b). Comparison of Delivery Pressure with Flow

Figures 7(a) and 7(b) present the variation of flow rate with suction and delivery pressures. Fig. 7(a) shows that a slight increase in suction pressure leads to an improvement in flow rate due to better inlet conditions, resulting in enhanced volumetric efficiency. In contrast, Fig. 7(b) indicates that an increase in delivery pressure causes a reduction in flow rate, which is consistent with the expected operating characteristics of oil pumps.

From Table IV, it can be observed that suction pressure values remain within a narrow range of approximately 0.951 to 0.970 in/Hg, indicating stable inlet conditions during testing. However, Sample 3 exhibits a significantly higher flow rate of 615 LPM, which corresponds to a comparatively lower delivery pressure of 1.32 kg/cm^2. This clearly demonstrates the inverse relationship between delivery pressure and flow rate.

For the remaining samples, delivery pressure values are relatively higher (ranging from 3.36 to 4.28 kg/cm^2), resulting in moderate flow rates between 403 and 473 LPM. This trend further confirms that increased discharge pressure leads to reduced flow due to higher hydraulic resistance within the system.

Temperature variations across all samples remain within a controlled range of 48.3°C to 54.7°C, indicating stable thermal operating conditions. The absence of significant temperature fluctuations suggests effective system design and proper heat management during testing.

The consistency of measured parameters across multiple samples indicates reliable sensor performance and stable system operation. Repeatability was verified through successive test runs, where only minor deviations were observed under similar operating conditions. This demonstrates the capability of the automated system to produce consistent and reproducible results.

Furthermore, the integration of PLC-based control with the SCADA system ensured synchronized operation and accurate real-time data acquisition. Compared to conventional manual testing methods, which rely on discrete readings and operator-dependent measurements, the proposed automated system provides continuous data acquisition and coordinated control, thereby reducing human-induced errors and improving measurement consistency and repeatability.

Overall, the results confirm that the developed system provides accurate, consistent, and efficient evaluation of oil pump performance under varying operating conditions, making it suitable for industrial testing applications.

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CONCLUSION

This work presents the design and development of a fully automated oil pump testing system, demonstrating the importance of automation, safety, and precision in industrial testing environments. The integration of a Programmable Logic Controller (PLC) with a LabVIEW-based data acquisition system enables accurate monitoring and control of key performance parameters, including pressure, flow rate, torque, temperature, and speed. This improves the reliability and repeatability of pump evaluation while reducing manual intervention and operational errors.

The implementation of real-time monitoring, automated test sequencing, and standardized report generation enhances testing efficiency and ensures consistent performance assessment. The developed system also reflects the practical application of modern industrial automation concepts, contributing to improved quality and process reliability.

The system demonstrated stable operation with suction pressure maintained within 0.951–0.970 in/Hg and flow rates ranging from 403 to 615 LPM under varying delivery pressures. The automated framework ensured consistent performance with minimal deviation across repeated trials, confirming improved repeatability and reliability compared to manual testing approaches.

The proposed system provides a scalable and industry-ready solution for automated oil pump testing and can be extended to support smart manufacturing applications. Further improvements can be made by incorporating high-pressure testing capabilities and advanced sensor integration to expand its applicability.

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