

Investigating the Relationship Between the Use of Precision Instruments in Installation Activities

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Abstract

Iran's oil industry, as one of the country's most vital economic sectors, requires advanced technologies to enhance productivity and reduce operational costs. This study investigates the application of precision instrumentation in the facilities of the Northern Region Oil Pipelines and Telecommunications Company, focusing on automation systems, control mechanisms, and calibration protocols. Given the critical importance of measuring, controlling, storing, and transferring the nation's production resources, the recognition, operation, and calibration of precision instrumentation equipment constitute a primary priority across all industrial sectors. With advancements in science and technology, the proliferation of electrical and precision instrumentation equipment in oil, gas, and petrochemical facilities has intensified the need for specialized technical inspection capabilities. However, due to the relatively recent emergence of electrical and precision instrumentation technical inspection as a discipline, consensus regarding the scope and operational description of this function remains limited, presenting ongoing challenges across various industrial sectors. This research examines technical criteria, operational procedures, and advanced inspection equipment utilized in pipeline facilities, with particular emphasis on programmable logic controller (PLC) systems, SCADA monitoring platforms, pressure and flow measurement devices, and comprehensive maintenance protocols. The findings demonstrate that precision instrumentation serves as the operational foundation for safe and efficient oil transportation, enabling the management of approximately 200,000 barrels of crude oil daily through integrated measurement, control, and monitoring systems. Key contributions include documentation of redundant control architectures, multi-parameter measurement integration strategies, and systematic calibration frameworks that ensure measurement accuracy and operational reliability in critical oil industry infrastructure.

Keywords: Oil Industries, Facilities, Precision Instruments.

INTRODUCTION

The Iranian oil industry represents a cornerstone of the national economy, requiring continuous technological advancement to maintain competitiveness and operational excellence. Precision instrumentation systems have emerged as indispensable components of modern oil facilities, enabling accurate measurement, reliable control, and comprehensive monitoring of complex processes. Despite the critical importance of these systems, the field of electrical and precision instrumentation technical inspection remains relatively young in Iran, with ongoing debates regarding standardization, scope definition, and best practice implementation across different operational contexts.

This study addresses a significant gap in the literature by providing comprehensive documentation of precision instrumentation applications in oil pipeline operations, an area that has received limited scholarly attention compared to other oil industry sectors (Chen, 2025; Meza et al., 2024; Omisola et al., n.d.; Taifa et al., 2025). While previous research has examined instrumentation in dams, power plants, and petrochemical facilities, the specific challenges and solutions associated with long-distance oil pipeline transportation—including geographic dispersion, harsh environmental conditions, and safety-critical operations—require dedicated investigation. This research contributes novel insights into the integration of *PLC*-based automation systems, *SCADA* monitoring platforms, and comprehensive calibration protocols specifically adapted to pipeline operational requirements.

Tabandeh and Jalalpour Barvaresh conducted a study in 2024 titled *Behavior Measurement of Arched Concrete Dams Using Precision Instrumentation*. In this study, the results of the instruments installed in the *Seymareh* Dam and Power Plant located in *Ilam* Province during operation were used. Based on the results of the deformation behavior analysis carried out by the first group of instruments (including pendulum, extensometer, joint meter, and thermometer), it was determined that the highest axial displacement was related to block 9 of the dam with a displacement of 15 mm and an evaluated curvature of 20 mm, which indicates the concentration of hydraulic pressure in this dam block. It was also determined that the flow in the bed is continuous and within the allowable limit and that there is no significant expansion of the plastic zone in terms of hydromechanical effects.

Review of the results of the 2014 earthquake with a magnitude of 6.1 on the Richter scale, when the reservoir water level was 667 meters, showed that the amount of displacement of the crest level was reported to be -2.4 mm, which did not have much effect on the change in the location of the dam crest. Based on the results of the interpretation of the graphs related to the standpipe instrumentation, it was determined that the left bank downstream of the dam has a higher concentration of water pressure than the right bank and the deformations in this front are greater, which is why it is recommended to use auxiliary pressure-reducing structures such as a water-tight wall or the construction of a clay blanket, as well as the creation of a gallery to reduce the pressure and control excessive pressure increase (Tabandeh & Jalalpour Barvaresh, 2024).

Moradi Sarkhanlov et al. conducted a study in 2024 entitled *Validation of Machine Learning Models for Interpreting and Predicting the Behavior of Dam Structures Using Instrumentation Data*. In this paper, considering 6 target variables defined by pendulum instrumentation, the behavior of the dam is modeled using selected machine learning models (Mata et al., 2021, 2023; Moradi Sarkhanlou et al., 2024; Salazar et al., 2015). The evaluation of the constructed models has been carried out using three error measurement indices (*R*, *MSE*, *MAE*) and model validation and verification techniques. Therefore, in this paper, an extensive work on the evaluation and validation of data-based models for analyzing the behavior of the studied dam has been presented. Validation techniques include historical data validation, prediction validation, and residual behavior over time. Thus, the *BRT* augmented regression tree model had the best adaptation and

accuracy in the learning and prediction sections of the studied arch dam behavior in the process of model evaluation and validation (Moradi Sarkhanlov et al., 2024).

In 2023, Manouchehr Sadeghi conducted a study entitled *Investigating the Application of New Technologies (Nuclear Precision Instruments, Nanotechnology, Artificial Intelligence, and Solar Energy) in Electricity and Instrumentation of Iranian Oil Industry Facilities*. The aim of this study is to investigate the application of nanotechnology, artificial intelligence, nuclear precision instruments, and solar energy in electricity and instrumentation of Iranian oil industry facilities. This study was conducted with the aim of identifying the advantages and disadvantages, challenges, and opportunities for the application of these technologies in the Iranian oil industry. This study used library, field, and interview methods. In the library section, scientific and research resources related to the subject under study were reviewed. In the field section, interviews were conducted with experts and specialists in the Iranian oil industry (Liravinia et al., 2023; Mirimoghadam & Ghazinoory, 2017; Sohrabi & Noorzai, 2023).

The findings of this study show that the application of nanotechnology, artificial intelligence, nuclear instrumentation, and solar energy in electricity and instrumentation of oil industry facilities can bring numerous benefits to this industry. Among these benefits are increasing the accuracy and precision of measurements, reducing maintenance and repair costs, increasing safety, and reducing pollution. The results of this study show that the application of nanotechnology, artificial intelligence, nuclear instrumentation, and solar energy in electricity and instrumentation of oil industry facilities in Iran has a high potential to improve the performance of this industry. Given the numerous benefits of these technologies, it is recommended that more research be conducted on the application of these technologies in the Iranian oil industry (Manouchehr Sadeghi, 2023).

Safari and Zanjani conducted a study in 2023 entitled *Design and Simulation of a Low Voltage and Low Power Current Mode Instrumentation Amplifier*. In this paper, an eight-transistor instrumentation amplifier with electronic tuning capability is presented that operates in the resistance transfer mode. The proposed instrumentation amplifier was simulated with 0.18 μm CMOS technology and a supply voltage of ± 0.7 V in Hspice software. The differential mode gain of the proposed instrumentation amplifier can be electronically changed by control voltages. Based on the simulation results, the common mode rejection ratio (CMRR) of the proposed instrumentation amplifier can be changed from 71.7 dB to 74 dB by changing the control voltage. The cutoff frequency of -3 dB for the common mode rejection ratio is also accessible in the range of 34.4 MHz to 40.8 MHz.

The power consumption of the proposed design varies from 234.57 microwatts to 338.73 microwatts in the tuning range. Time domain analysis for the proposed design shows that for a peak-to-peak input signal of 20 microamperes, the maximum total harmonic distortion (THD) for different frequencies is 13.2%. The output impedance of the proposed instrumentation amplifier can be changed from 860 to 1640 ohms by changing the control voltage (Safari & Zanjani, 2023). Mirbeigi in 2021 conducted a study entitled *Investigation and Analysis of the Seepage Performance of the Soleiman Shah (Shohada) Earthen Dam with Respect to Instrumentation Results*. In this study, the investigation of seepage in the Soleiman Shah Dam by comparing it with

the instrument results is the main objective of the study. The present research method is carried out in software and with *MATLAB* and *GeoStudio* software, *Seep/W* branch.

In modeling, first, the accuracy of the instrument results was compared with the modeling in the software in the *MATLAB* program to calculate the seepage from the body of the *Suleimanshah* earthen dam using the finite element method, and then the results of this program were compared with the results of the *GeoStudio* software, the *Seep/W* module, and the dam's instrument reports. The hydraulic conductivity in the dam was selected as a non-deterministic parameter and it was considered as a random field. To validate the results of the numerical analysis in this thesis, the seepage discharge values obtained from the model simulation in the code written were compared with the values obtained from the *GeoStudio* software, and the results obtained indicate the high accuracy of the written code. The model used in the numerical simulation is the *Suleimanshah* Dam, which has been numerically examined in homogeneous and heterogeneous forms.

Next, the changes in the dam seepage flow rate with increasing or decreasing the upstream water height were examined and compared in *GeoStudio* software and the results of the precision instrument. The result was shown in a graph, which showed that the dam seepage behavior was acceptable. Finally, the effect of the heterogeneity coefficient was examined. By increasing this coefficient, it was clearly observed that the seepage flow rate in the dam decreases (Mirbeigi, 2021).

In 2021, Asgari et al. conducted a study entitled *The Role of Installation and Reading of Precision Instruments in Optimizing Structural Calculations for Temporary Maintenance and Final Concrete Cover of the Alborz Tunnel Complex (Second Section of Tehran-North Freeway)*. This article introduces the precision instruments installed in the *Alborz* Tunnel (convergence gauge, elongation gauge, load gauge, and strain gauge) and the critical limits of each instrument. The solutions required if the recorded number exceeds the critical limits are stated.

More than 50 instrumentation stations were installed in the *Alborz* Tunnel, mostly convergence gauges. In some stations, instrumentation issued warnings about instrument readings, which prevented the occurrence of hazards by completing and increasing reinforcements or lining in that area. The term instrumentation refers to a wide range of instruments for measuring changes in physical quantities that engineers use in their wide field of activity, such as rock mass displacement, force applied to the retention system (primary and final), groundwater pressure, etc. The work of collecting, processing, displaying, and analyzing data obtained from instrumentation is called *behaviorography* (Asgari et al., 2021).

In 2020, Hamiti Vaghef and Alii conducted a study entitled *The Importance of Water Measurement and Instrumentation in Reducing Consumption and Repairs of Thermal Power Plants*. In this article, the special importance of measurement and the role of water instrumentation in the occurrence of the above problems are examined. The effect of flowmeters, conductivity meters, and water analyzers on the power plant water supply and circulation cycles, cooling towers, the amount of blowdown, water intake, cooling fans, etc., has been studied in detail in this article and suggestions have been made to improve the situation. This article predicts that in some power

plants with very low concentration numbers, the modification of water instrumentation will result in a more than 25% reduction in the power plant water consumption (Hamiti Vaghef & Alii, 2020).

Khobroi Pak and Nikouyeh conducted a study in 2019 entitled *Investigation of Seepage from the Foundation and Body of the Earthen Dam in Bijar City* using numerical software and precision instrument data. In this study, using the finite element method and selecting the earthen dam in Bijar city as a case study, a model of the above dam was drawn using the *Seep/W* software and the numerical model was calibrated by performing a back-analysis using precision instrument data and then the dam was analyzed by increasing the reservoir water level to the normal water level. By examining the results, the leakage flow rate from the dam was calculated and the status of the phreatic line and the flow lines and potential inside the body and foundation of the dam were determined. In the maximum permissible water height state, compared to the stable seepage water height state, due to the increase in the upstream water level, the position of the phreatic line in the dam has moved higher.

According to the results of the numerical model and the information from the precision instruments, the performance and placement of the drain have been carried out correctly, and the level of the phreatic line in the case of the maximum permissible water height upstream of the dam is reported to be acceptable. According to the flow arrows in the numerical model in the body and foundation of the dam, most of the seepage occurs through the body of the dam, and seepage from the foundation of the dam is very small, so that it can be ignored (Khobroi Pak & Nikouyeh, 2019).

Amiri and Vahdati conducted a study in 2018 entitled *Analysis of the Settlement Time of Earth Dams and Its Comparison with the Results from Precision Instruments*. In this study, the results from precision instruments (installed settlement gauges) in *Sedgavshan* are compared with the modeling results and a proper analysis of the operation process of the instruments and the proximity of the results of the instruments to the results of the finite element method are presented. Also, in cases where the difference between these two cases exceeds the permissible and reasonable limits, the correct result is related to the operation of the precision instrument or modeling with the software. For this purpose, the necessary data for modeling was collected from the *Gavshan* earthen dam and *Plaxis* software was used for modeling. The results of modeling and precision instrument reports of dams show that materials that are compacted below the optimal moisture content have a lower settlement rate than materials that are compacted above the optimal moisture content, which is clear in both the precision instrument results and the analysis results. Also, in the instrumentation of the *Gavshan* dam, a number of instruments are of inappropriate quality (Amiri & Vahdati, 2018).

In 2018, Mazaheri et al. conducted a study entitled *Numerical Investigation of Earthen Dam Behavior and Its Comparison with Instrumentation Data; Case Study of the Maruk Dam in Lorestan*. In this study, the behavior of the *Maruk* earthen dam with a clay core, which has a height of 68 meters, was investigated using numerical modeling of the *GeoStudio* software and precision instruments. First, the geometry of this earthen dam was modeled in the software and the vertical stresses in the core and the maximum settlement during construction were determined. Then, the

results were compared with the readings of precision instruments installed in different parts of the dam body.

Comparison of numerical analysis results and instrument readings shows that when the dam construction level is at an altitude of 1590 meters above sea level (31 meters below the dam crest), the maximum settlement measured at the end of dam construction with the *INC 10-1* instrument installed 4 meters upstream of the dam axis is 81 cm, and the numerical analysis results show the settlement value at the same point to be 80 cm. The highest amount of bowing and vertical settlement in the long term occurs approximately in the middle of the dam. The value of the bowing coefficient is between 0.73 and 1, which indicates that the head of the *Maruk* dam is in a stable state (Mazaheri et al., 2018).

In 2017, Farahani and Montazeri conducted a study titled *Measuring Multiphase Flow of Oil and Gas Using Virtual Instrumentation*. In this paper, measuring multiphase flow using virtual instrumentation is investigated. A nonlinear observer is applied to the Navier-Stokes equations governing fluids using the extended Kalman filter, and the two-phase oil and gas flow rate is estimated. This estimation is performed using the finite element method and the cumulative Kalman filter, in two scenarios using output measurement data and input measurement information, and finally the estimation results are compared with the actual process information available in the industry.

In this article, we did not seek to directly measure the flow of multiphase fluids, but rather, by using variables (such as pressure, temperature, single-phase flow at the outlet of the unit or the inlet of the unit along with the volume fraction) that can be measured directly, we have obtained the input flow with high accuracy without using the primary flow measurement element. By comparing the two measurement methods at the inlet of the refinery and the outlet of the refinery, it is observed that the accuracy and repeatability of the method used is very high, so that the estimation error based on the input is 0.142% and based on the output is 1.036%. Accordingly, although this information does not match the output system, fortunately it matches the information of the input measurement system, so in addition to being able to replace the system at that point, it also can support the existing system (Farahani & Montazeri, 2017).

In 2014, Asadian et al. conducted a study titled *Behavioral Mapping of the Dousti Dam until the End of Construction using Instrumentation Data and Numerical Analysis*. In this study, first, the correctness of the instrumentation installed in the *Dousti* Dam was evaluated, then, based on the results of the instrumentation and numerical analysis, the maximum settlement values, the vertical stress values in the core, and the arching phenomenon were examined. To perform numerical analyses, *Geostudio 7.1* software was used, which, in addition to performing simultaneous analyses, has the capability of analyzing staged construction and performing two-dimensional consolidation. The behavioral models used in the analysis are the linear elastic model and the Mohr-Coulomb fully elastoplastic behavioral model. From the comparison of the modeling and instrumentation results, it can be concluded that the *Dousti* Dam is in stable and safe conditions (Asadian et al., 2014).

The primary objectives of this research are: (1) to document the comprehensive precision instrumentation architecture implemented in Northern Region oil pipeline facilities, (2) to analyze the integration of measurement systems with *PLC*-based automation and *SCADA* monitoring platforms, (3) to evaluate maintenance and calibration protocols ensuring measurement accuracy and system reliability, and (4) to identify best practices and technological opportunities for enhancing precision instrumentation applications in oil industry operations. The benefits of this study extend to industry practitioners, regulatory authorities, and academic researchers seeking to understand the critical role of precision instrumentation in ensuring safe, efficient, and environmentally responsible oil transportation operations. The practical implications include potential improvements in operational efficiency, reduced maintenance costs, enhanced safety performance, and informed technology adoption decisions for future facility development and modernization projects.

RESEARCH METHOD

This study employed a mixed-method approach combining descriptive-analytical and case study methodologies to investigate the relationship between precision instrumentation and installation activities in oil industry facilities. The research was conducted at the Northern Region Oil Pipelines and Telecommunications Company, focusing on the application of precision instruments in automation and control systems.

The research was conducted at the Northern Region Oil Pipelines and Telecommunications Company, which operates with an organization of over 355 personnel. The company manages oil transfer centers at Neka, Sari, Golpol, and Orim, transporting approximately 200,000 barrels of crude oil daily from Caspian Sea countries through 30 and 32-inch pipelines. These pipelines traverse difficult mountainous terrain and forests of Mazandaran province to Tehran and Tabriz refineries.

Data collection was performed through three primary methods:

1. **Library Research:** Comprehensive review of scientific literature, technical documentation, and research resources related to precision instrumentation in oil industry facilities. This included analysis of international standards, technical manuals, and previous studies on automation systems, *PLC* technology, and instrumentation calibration procedures.
2. **Field Observation:** Direct observation and technical inspection of precision instrumentation equipment installed at oil transfer centers. This included examination of programmable logic controllers (*PLCs*), *SCADA* systems, pressure transmitters, flow meters, temperature sensors, and control valves. Field observations were documented through technical checklists and photographic evidence.
3. **Expert Interviews:** Semi-structured interviews with instrumentation engineers, control system technicians, maintenance personnel, and operations managers at the Pipeline and Telecommunications Company. Interview questions focused on technical specifications, operational challenges, calibration procedures, maintenance protocols, and the role of precision instruments in ensuring safe and efficient operations.

The study focused on the following categories of precision instrumentation equipment:

1. Control Systems: Programmable Logic Controllers (PLC) with redundant configuration, SCADA monitoring systems based on Windows CE platform, and Human-Machine Interface (HMI) systems.
2. Pressure Measurement: Electronic pressure gauges, pressure transmitters with 4-20 mA output signals, and pressure protection switches.
3. Flow Measurement: Orifice plate flow meters, differential pressure transmitters, and flow indicators.
4. Temperature Measurement: Electronic thermocouples, temperature transmitters, and thermal protection systems (TSV).
5. Level Measurement: Ultrasonic level gauges, level switches (Low, High, High-High configurations), and tank level monitoring systems.
6. Control Actuators: Control valves, pressure safety valves (PSV), magnetic valves, and automated pump control systems.

The collected data were analyzed using the following approaches:

1. Technical Specifications Analysis: Systematic review and categorization of technical specifications, operational parameters, and performance characteristics of precision instruments. This included analysis of accuracy levels, signal ranges (4-20 mA), measurement ranges, and calibration standards.
2. Process Flow Analysis: Examination of signal flow from field instruments through transmitters to PLC systems and control actuators. Analysis included mapping of input/output relationships and control logic implementation.
3. Comparative Literature Review: Synthesis of findings from previous studies on precision instrumentation applications in similar industries (dams, power plants, petrochemical facilities) to identify best practices and lessons learned applicable to oil pipeline operations.
4. Descriptive Statistical Analysis: Compilation and presentation of operational data including daily transfer capacity (200,000 barrels), pipeline specifications (30-32 inch diameter), organizational structure (355 personnel), and geographical coverage of the oil transfer network.

The study examined the following key variables:

1) Independent Variables:

- a) Types of precision instruments (pressure, flow, temperature, level measurement devices)
- b) Instrumentation installation procedures and configurations
- c) Calibration and maintenance protocols

2) Dependent Variables:

- a) Operational efficiency and reliability of oil transfer systems
- b) Safety performance and process control accuracy
- c) Maintenance requirements and equipment readiness

This study was subject to the following limitations:

1. **Geographic Scope:** The research was limited to the Northern Region Oil Pipelines and Telecommunications Company facilities, and findings may not be generalizable to other regions or oil industry sectors.
2. **Time Constraints:** Data collection was conducted during normal operational periods, which may not capture performance under all possible operational scenarios or emergency conditions.
3. **Technology Focus:** The study primarily focused on PLC-based automation systems and conventional precision instruments, and did not extensively examine emerging technologies such as wireless sensors or advanced AI-based control systems.

Proprietary Information: Some detailed technical specifications and operational data could not be disclosed due to confidentiality and security considerations in the oil industry.

RESULTS AND DISCUSSION

Overview of Precision Instrumentation System at Northern Region Oil Pipelines

The Northern Region Oil Pipelines and Telecommunications Company operate a comprehensive precision instrumentation system that manages the transportation of approximately 200,000 barrels of crude oil daily from Caspian Sea countries. The system spans four major oil transfer centers (Neka, Sari, Golpol, and Orim) connected through 30 and 32-inch pipelines traversing mountainous terrain and forests of Mazandaran province to Tehran and Tabriz refineries.

The automation and control infrastructure is entirely based on Programmable Logic Controller (PLC) technology with redundant system configuration. This redundancy ensures continuous operation by utilizing two PLCs: one active and one standby. In the event of CPU or module failure in the active system, automatic switching to the standby CPU occurs, preventing operational disruptions in the crude oil transfer process.

Control and Automation System Architecture

The control system architecture consists of three integrated layers:

Field Instrumentation Layer: This layer comprises sensors and transmitters installed at strategic points throughout the pipeline network. Signals from converters and transmitters are collected from field locations and transmitted to the control layer. The instrumentation includes pressure transmitters, flow meters using orifice plate methodology, electronic thermocouples, and ultrasonic level gauges.

Control Processing Layer: The PLC system receives signals from field instrumentation, performs computational operations and decision-making processes, and generates control commands. The system processes input signals and produces output control signals to actuators, executing the required control operations for pressure regulation, flow management, and temperature control.

Monitoring and Interface Layer: The SCADA monitoring system operates on Windows CE platform and is installed on four computers and one server in the control room. This system provides operators with real-time visualization of process parameters, including fully graphical

process displays created as simulations, archive displays and error sampling, process image sampling, and automated report generation for documenting machine operations and process routines.

Critical Process Measurements and Control Functions

Pressure Measurement and Control

Pressure measurement and control constitute the most critical processes in oil transfer operations. Electric pressure gauges and pressure transmitters measure inlet and outlet pressures at transfer centers and critical pipeline points. The transmitters generate output signals that are processed by the PLC system to execute control operations through pressure control valves.

The pressure control mechanism operates through regulation of inlet and outlet valves. Operators can adjust line pressure by modifying the degree of valve opening or closing. The system supports both manual and automatic control modes via PLC, providing operational flexibility. All pressure control actuators are equipped with dual-mode operation capability, ensuring control continuity under various operational scenarios.

Flow Measurement System

Flow measurement employs the orifice plate differential pressure method. The system calculates flow rate using the equation $Q = K\sqrt{P}$, where Q represents flow rate, K is the flow coefficient, and P is the pressure difference. Pressure transmitters convert the differential pressure created by the orifice plate into standardized 4-20 mA electronic signals. These signals are transmitted to the PLC system, which applies programmed functions to convert pressure differential into actual flow values for display and control purposes.

Temperature Monitoring

Electronic thermocouples provide temperature measurement throughout the system. The PLC directly receives and processes thermocouple outputs without intermediate signal conversion. Temperature values are displayed graphically on the monitoring system, enabling operators to track thermal conditions in real-time and identify potential issues before they escalate to critical levels.

Tank Level Measurement and Control

The tank level measurement system utilizes ultrasonic height gauges providing high-precision measurements. These transmitters generate electrical signals proportional to tank level height, which are received and processed by the PLC. The system displays level information as graphical charts and generates overflow and low-level alarms when thresholds are exceeded.

Additionally, level switches are installed at multiple tank positions, operating in three critical modes: Low Level, High Level, and High-High Level. These switches provide redundant protection by delivering commands and alarms to the control system during critical conditions, preventing tank overflow or complete emptying scenarios.

Pump Capacity Control System

Oil transfer capacity in the system is regulated through the operation of four main electric pumps in each pump house, configured to operate in parallel. Maximum transfer capacity is achieved when all four pumps operate simultaneously, while minimum capacity is obtained with single-pump operation. Due to the fixed-speed nature of electric motors, capacity adjustment is accomplished exclusively through pump parallel rather than variable speed control.

Comprehensive Instrumentation Equipment Inventory

The control process utilizes the following precision instrumentation equipment:

1. Pressure transmitters and indicators
2. Temperature transmitters and electronic thermocouples
3. Flow measurement indicators using orifice plate methodology
4. Pressure protection switches and safety systems
5. Pressure safety valves (PSV) and temperature safety valves (TSV)
6. Pressure control valves and magnetic valves
7. Density measuring devices
8. Vibration monitoring devices for motors and rotating machinery
9. Environmental temperature indicators

Maintenance and Calibration Services Performed

The Precision Instrumentation Unit executes comprehensive maintenance and calibration programs to ensure equipment readiness and measurement accuracy. Services are performed on monthly and annual schedules, providing accuracy coefficients for system performance. Key maintenance activities include:

1. Programmable controller maintenance and software updates
2. Electronic indicator and recorder adjustment and calibration
3. Thermocouple calibration and thermal system adjustment
4. Protective switch servicing and adjustment
5. Pressure transmitter adjustment and verification
6. Battery system maintenance and charger servicing
7. Inverter system maintenance and testing
8. Pressure indicator servicing and adjustment
9. Pressure safety valve calibration and testing
10. Control valve servicing and functional testing
11. Turbine vibration system servicing and testing
12. Density meter calibration and verification
13. Water distillation device inspection and servicing
14. Electrical measuring device calibration

Critical Role of Precision Instrumentation in Oil Pipeline Operations

The findings demonstrate that precision instrumentation serves as the foundation for safe and efficient oil pipeline operations in the Northern Region. The implementation of redundant PLC systems with automatic failover capabilities addresses the critical nature of oil transfer operations, where any control system failure could result in significant operational disruptions and safety hazards.

This approach aligns with findings from Asadian et al. (2014) regarding behavioral monitoring of critical infrastructure, where precision instrumentation proved essential for maintaining operational stability. The redundant system architecture identified in this study reflects industry best practices for high-reliability applications, ensuring continuous monitoring and control even under component failure scenarios.

Integration of Measurement Systems for Comprehensive Process Control

The study reveals that the Northern Region employs an integrated measurement approach encompassing pressure, flow, temperature, and level monitoring. This multi-parameter monitoring strategy enables operators to maintain comprehensive situational awareness and respond proactively to process deviations. The standardization of signal transmission using 4-20 mA protocols facilitates system integration and reduces compatibility issues between different instrumentation vendors.

The application of orifice plate flow measurement with differential pressure transmitters represents a well-established and reliable methodology. As noted by Varvani Farahani and Montazeri (2017) in their work on multiphase flow measurement, the conversion of pressure differential to flow rate using the relationship $Q = K\sqrt{P}$ provides accurate flow quantification when properly calibrated. The integration of these measurements into the PLC system enables real-time flow monitoring and automated control responses.

Pressure Control as Primary Safety Mechanism

The results highlight pressure measurement and control as the most critical operational parameters in oil transfer operations. The dual-mode control capability (manual and automatic) provides operational flexibility while maintaining safety margins. This approach is consistent with findings from Tabandeh and Jalalpour Barvaresh (2024), who emphasized the importance of continuous pressure monitoring in critical infrastructure applications.

The implementation of control valves at inlet and outlet points enables precise pressure regulation across the pipeline network. The ability to adjust valve opening degrees provides granular control over system pressure, preventing overpressure conditions that could compromise pipeline integrity. The integration with PSV safety systems provides additional protection layers, automatically relieving excess pressure when control systems cannot maintain safe operating limits.

Advanced Monitoring and SCADA Integration

The Windows CE-based SCADA system provides operators with comprehensive visualization capabilities, including graphical process representations, historical data archiving, and automated reporting. These features enhance operational decision-making by presenting complex process information in accessible formats. The ability to display process parameters graphically enables operators to identify trends and anomalies more rapidly than numerical displays alone.

This monitoring approach resonates with Moradi Sarkhanlov et al. (2024), who utilized instrumentation data for predictive modeling in dam structures. The archival capabilities of the SCADA system enable similar data-driven analysis approaches for pipeline operations, potentially supporting predictive maintenance strategies and operational optimization initiatives.

Multi-Layer Tank Level Safety Systems

The implementation of ultrasonic level gauges combined with discrete level switches demonstrates a defense-in-depth approach to tank level management. The continuous measurement provided by ultrasonic sensors enables precise inventory management and transfer optimization, while discrete switches provide independent alarm and shutdown capabilities at critical levels.

The three-tier switch configuration (Low, High, High-High) aligns with safety instrumented system (SIS) design principles, providing multiple intervention points before reaching catastrophic failure conditions. This redundant protection strategy prevents both overflow scenarios, which pose environmental hazards, and tank emptying conditions, which could damage pumping equipment or interrupt crude oil supply to downstream facilities.

Comprehensive Maintenance and Calibration Framework

The structured maintenance program implemented by the Precision Instrumentation Unit addresses a critical aspect identified in the literature review regarding the importance of calibration for measurement accuracy. Regular calibration of pressure transmitters, temperature sensors, flow meters, and safety valves ensures measurement reliability and prevents drift-induced errors that could compromise operational decisions.

The monthly and annual maintenance schedules reflect a proactive approach to equipment management, addressing potential failures before they impact operations. This strategy is consistent with Hamiti Vaghef and Alii (2020), who demonstrated that proper instrumentation maintenance and calibration could achieve significant performance improvements and cost reductions in thermal power plants. Similarly, the Northern Region's systematic calibration program ensures measurement accuracy and extends equipment service life.

Capacity Control Through Pump Configuration

The study reveals that transfer capacity management relies on pump paralleling rather than variable speed control. While this approach provides discrete capacity steps, it offers operational

simplicity and reliability advantages. Fixed-speed pumps typically exhibit longer service life and reduced maintenance requirements compared to variable frequency drive (VFD) systems, though at the cost of reduced operational flexibility.

The four-pump configuration enables reasonable capacity modulation between minimum (single pump) and maximum (four pumps) operating points. This design provides operational flexibility to match varying crude oil supply rates from Caspian Sea countries while maintaining efficient pump operation within design parameters. The precision instrumentation system facilitates coordinated pump startup and shutdown sequences, preventing pressure transients that could stress pipeline infrastructure.

Comparison with Precision Instrumentation in Other Industries

The instrumentation approach identified in oil pipeline operations shares significant similarities with applications in other critical infrastructure sectors. Khobroi Pak and Nikouyeh (2019) demonstrated the use of precision instruments for seepage monitoring in earthen dams, where continuous measurement and automated alarming prevent catastrophic failures. Similarly, the Northern Region's continuous pressure and level monitoring prevents operational excursions that could result in pipeline ruptures or environmental releases.

Mazaheri et al. (2018) utilized precision instrumentation data to validate numerical models of earthen dam behavior, demonstrating the value of instrumentation for understanding complex infrastructure performance. The Northern Region's SCADA archival capabilities enable similar applications, where historical instrumentation data could support hydraulic modeling efforts and operational optimization studies. The integration of measurement, control, and data archiving creates opportunities for advanced analytics and predictive maintenance strategies.

Challenges and Opportunities for Technology Enhancement

While the current instrumentation system demonstrates effective performance, opportunities exist for technology enhancement. Sadeghi (2023) identified emerging technologies including nuclear precision instruments, nanotechnology, artificial intelligence, and solar energy as potential improvements for oil industry facilities. The integration of AI-based analytics with existing SCADA data could enable predictive failure detection, optimizing maintenance scheduling and reducing unplanned downtime.

The geographic challenges posed by mountainous terrain and remote pipeline locations could benefit from wireless instrumentation technologies, reducing installation costs and improving measurement density. However, such implementations must address cybersecurity considerations and ensure measurement reliability under harsh environmental conditions. The young nature of electrical and precision instrumentation technical inspection in the oil industry, as noted in the introduction, suggests continuing evolution of best practices and standardization efforts.

Implications for Oil Industry Operations and Safety

The findings underscore the critical dependence of modern oil pipeline operations on precision instrumentation systems. The 200,000 barrels per day throughput managed by the Northern Region represents significant economic value and energy security importance for Iran. The instrumentation system's reliability directly impacts operational continuity, environmental protection, and personnel safety.

The redundant control architecture, comprehensive measurement coverage, and systematic maintenance programs identified in this study represent industry best practices that could be applied to other oil pipeline systems. The integration of multiple measurement modalities (pressure, flow, temperature, level) provides operators with comprehensive situational awareness, enabling proactive intervention before process deviations escalate to emergency conditions.

Study Limitations and Future Research Directions

This study focused primarily on the technical specifications and operational characteristics of precision instrumentation systems. Future research could quantify the economic benefits of precision instrumentation through analysis of downtime reduction, maintenance cost optimization, and operational efficiency improvements. Additionally, comparative studies examining instrumentation approaches across multiple oil pipeline systems could identify region-specific optimization opportunities and best practice variations.

The integration of emerging technologies such as machine learning for predictive maintenance, as demonstrated by Moradi Sarkhanlov et al. (2024) in dam applications, represents a promising research direction. Investigating the application of these advanced analytics techniques to oil pipeline instrumentation data could reveal opportunities for enhanced operational optimization and failure prevention. Furthermore, research into cybersecurity aspects of networked instrumentation systems would address an increasingly important operational concern.

CONCLUSION

This study comprehensively examined precision instrumentation at the Northern Region Oil Pipelines and Telecommunications Company, identifying it as the core operational backbone for safely transferring ~200,000 barrels of crude oil daily through a robust three-layer architecture integrating field sensors, redundant PLC-based controls, and Windows CE SCADA monitoring. Key findings highlight multi-parameter measurements (pressure, flow, temperature, tank levels) for process control and safety, bolstered by defense-in-depth redundancies, multi-tiered safety switches, and rigorous maintenance/calibration protocols that ensure resilience amid dispersed, harsh environments—offering a replicable best-practice model for critical infrastructure. For future research, investigations should quantify economic/safety impacts (e.g., ROI, downtime reduction, incident prevention) while exploring IIoT integration, machine learning for predictive maintenance/anomaly detection, comparative regional studies, and cybersecurity enhancements to optimize efficiency and safeguard national energy systems.

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