

# Design of Leakage Monitoring System for Non-Membrane Impervious Tank Based on Multi-Electric Method Fusion

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**Abstract:** To address leakage caused by the deterioration of non-membrane impervious structures, such as impervious tanks used in industrial and mining sites, this paper develops a leakage monitoring system based on multi-electrical method fusion. By jointly analyzing the spatial potential distribution and the amplitude and phase parameters obtained from the complex resistivity method, the proposed system can identify leakage from industrial and mining wastewater facilities. The portable detection system developed has been verified by experiments, and its detection results have good reliability.

## 1 Introduction

Pollutants in industrial wastewater often exist in complex forms, posing serious threats to the ecological environment and public health<sup>[1]</sup>. Industrial wastewater contains various toxic substances such as heavy metals, organic dyes, volatile organic compounds (VOC), drug residues and emerging pollutants<sup>[2]</sup>. Mining and mineral processing consume large quantities of water. The discharged wastewater often contains toxic organic compounds, flotation reagents, and heavy metal pollutants at concentrations that may exceed WHO limits.

Current leakage detection methods for non-membrane impervious structures mainly include leakage-flow monitoring<sup>[3]</sup>, geophysical methods such as the natural electric field method<sup>[4]</sup>, high-density resistivity method<sup>[5]</sup>, and transient electromagnetic method<sup>[6]</sup>, as well as optical-fiber methods such as distributed temperature sensing<sup>[7]</sup>. However, these methods have obvious limitations in practical engineering application: The traditional pressure test can only provide an integral "leakage/no leakage" judgment, lacking the ability to accurately locate the leakage point in space; although geophysical electrical exploration is harmless, its effect is limited by strict seepage conditions and environments, such as natural electric field method is difficult to locate small leakage, high density resistivity method has low resolution, and transient electromagnetic method has depth and blind area limitations; in addition, the effectiveness of distributed temperature sensing depends heavily on the temperature difference between leakage water and environmental medium.

This paper proposes a new leakage detection approach based on the fusion of multiple electrical methods, which can effectively identify the leakage point of nonmembrane impervious structures.

## 2 Monitoring Principle

### 2.1 Complex Resistivity Method

The complex resistivity method is a geophysical exploration method based on the measurement of electrical parameters. The amplitude parameters reflecting current resistance and the phase parameters characterizing polarization effect are obtained by measuring the medium response under the action of alternating current electric field. In this study, the leakage location of polyurea coating was accurately located by analyzing the potential distribution and complex resistivity parameters combined with the characteristics of polyurea coating pool.

When a sinusoidal voltage or current with a given angular frequency is applied to both sides of the tank, the current or voltage signal output from the measuring terminal will eventually reach a steady state. Using the phasor method, the ratio of the voltage phasor to the current phasor is defined as the complex impedance  $Z$  at both ends of the electrode

$$Z = \frac{\dot{U}}{\dot{I}} = \frac{U}{I}(\angle\varphi_u) - (\angle\varphi_i) = |Z|\angle\varphi_z$$

In the formula  $\dot{U} = U\angle\varphi_u$ ,  $\dot{I} = I\angle\varphi_i$ . The modulus  $|Z|$  of  $Z$  is called impedance mode (also called amplitude), and its argument  $\angle\varphi_z$  is called impedance angle (also called phase), which is the difference between voltage phase and current phase. In the complex resistivity measurement experiment, the impedance mode  $|Z|$  and phase angle  $\angle\varphi_z$  are observed for analysis and judgment.

Based on the above principle, the observation of complex resistivity parameters needs to obtain voltage and current signals through the measurement system, and analyze their amplitude and phase characteristics<sup>[8]</sup>.

## 2.2 Potentiometric Mapping

The basic principle of leakage detection using the potentiometric mapping method is to connect the two terminals of a high-voltage DC power supply to opposite sides of the membrane and locate the leak by measuring the potential distribution of different points in the medium under the membrane. If the membrane is damaged, its high resistance characteristics are destroyed, and current flows from the positive terminal of the power supply, passes through the leakage path, and returns to the negative terminal, thereby forming a closed current loop [9].

## 3 Monitoring System Design

### 3.1 Overview of the Monitoring System

A leakage detection system for non-membrane impervious tanks was developed, which integrates high-performance hardware and customized software. The hardware consists of a TAG-101D signal source, an HVP-300D power amplifier, an electrode switching box, and a PXIe-1078 high-speed data acquisition unit. The software is developed based on LabVIEW platform to realize equipment control, data acquisition and processing. The collected data are stored and managed by MySQL database. The workflow is as follows: The electrode switching is controlled by LabVIEW program instruction, and the electric signal excitation is applied after signal amplification. Meanwhile, the voltage response data is collected at high speed, and finally the leakage point location analysis is realized.

### 3.2 Hardware Section

The power supply unit provides adjustable AC and DC excitation signals for the electrode array. The amplified driving current is injected into the electrode array to generate a measurable electric field.

The circuit gating box consists of two modules: DC-AC signal conversion and load switching. The high-precision control unit ensures stable signal output and accurate operation of the equipment. The central controller drives the relay array to realize multi-channel switching and ensures operation reliability through communication protocols. For inactive electrodes, the switching board connects all required channels to establish a complete measurement loop.

The signal acquisition and processing unit has a modular design and integrates high-speed acquisition and real-time processing functions. The acquisition unit uses a PXIe-6358 board with 16 differential analog input channels, with sampling voltage accuracy between  $\pm 2688\mu\text{v}$  and  $\pm 10\text{v}$ , maximum sampling rate of 250kS/s and 16-bit resolution; the processing part is PXIe-1078 chassis, equipped with a processor that runs the LabVIEW system for data analysis, visualization, and control of the circuit gating box through the RS485 bus. (see Figure 1).

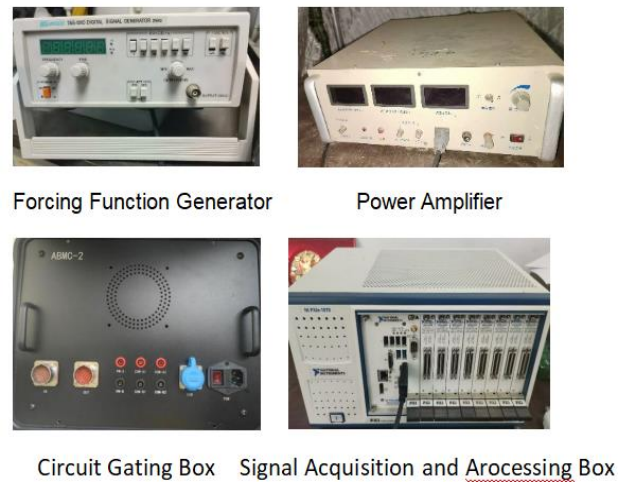


Figure 1. Diagram of the equipment.

### 3.3 Software Section

The experimental system was developed mainly on the LabVIEW platform and consists of three modules: command-file input, data acquisition, and data storage.

In data acquisition, the device needs to switch the positions of power supply electrodes according to preset sequence. Command files are edited in Excel and imported into LabVIEW, enabling precise control of the relay modules.

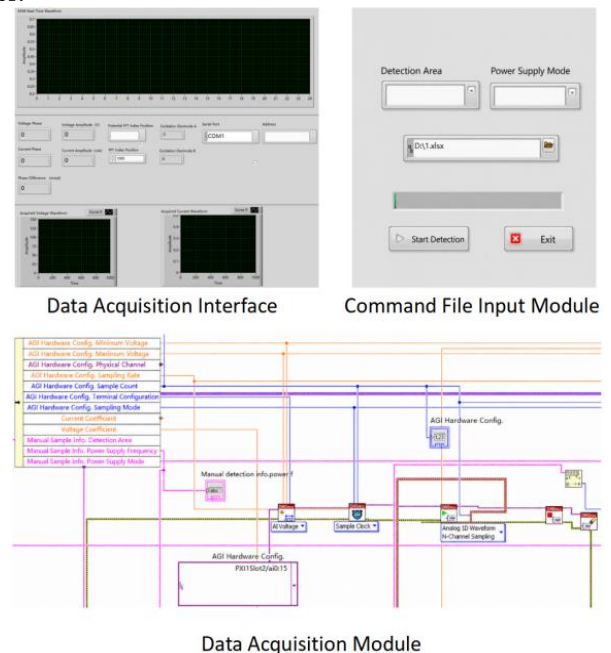


Figure 2. Schematic diagram of the software.

Experimental data are acquired using the PXIe-6358 data acquisition board. In the configuration stage, it is necessary to set the voltage range, physical channel parameters, sampling rate and sampling points of the acquisition card, and complete the wiring-mode setting. The data acquisition module (DAQ-mx) realizes the acquisition start and stop control by creating channel task sequences. The original acquisition data is processed by Fast Fourier Transform (FFT) [10] and converted to frequency domain

to obtain the target frequency domain data.

The data storage module establishes a communication connection between LabVIEW and the MySQL database through the ODBC interface, and converts the collected data and configuration information into SQL statements for storage through cooperative operation with Navicat client. When data processing is required, a query statement is used to filter the target data, and an Excel-format file is generated through VI export and saved to designated path(see Figure 2).

### 4 Experimental Results and Analysis

This experiment was conducted at the pollution transport and monitoring test site of a research institute in Beijing. Twenty-five electrodes were arranged in a  $5 \times 5$  array. The electrode spacing was 0.15m. The outer electrode at the bottom of the tank was 0.05m away from the bottom of the tank.

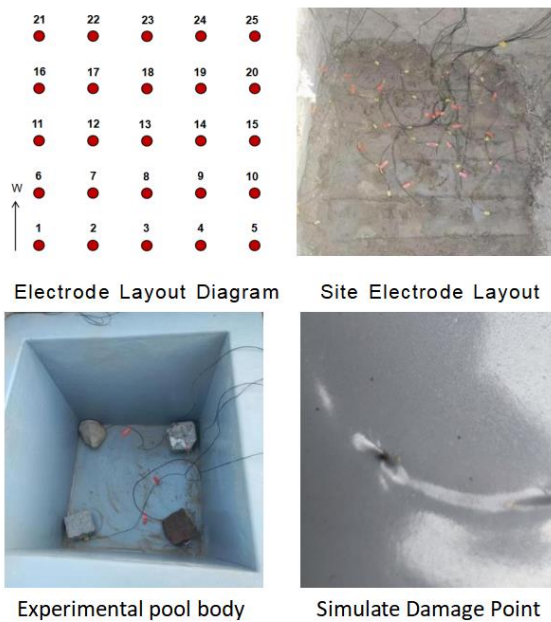


Figure 3. Experimental site layout diagram.

A cement tank with a length of 0.91 m, a width of 0.91 m, a height of 0.73 m, and a wall thickness of 0.18 m was embedded. A uniform 2 mm polyurea coating was applied to the bottom and inner wall of the tank. A 2 mm defect was introduced in the polyurea coating at the bottom of the tank, and the defect was located between detection points No. 9 and No. 14, corresponding to coordinates (4, 2) and (4, 3). (see Figure 3).

When the power supply voltage is 50V and the operating frequency is 1000Hz, the two-dimensional distribution of potential, impedance mode and phase after polyurea damage is shown in the figure. The impedance modulus(see Figure 4) at the damage point (coordinates (4,2)-(4,3)) is lower than that in other areas, the phase shift(see Figure 5) is increased, and the potential(see Figure 6) is increased. The electrical response characteristics are highly consistent with the expected leakage behavior, and the variation trends of impedance mode, phase and poten-

tial are synchronous. It is verified that the fusion of complex resistivity parameters and potential distribution can realize the leakage monitoring requirements of non-membrane impermeable structures.

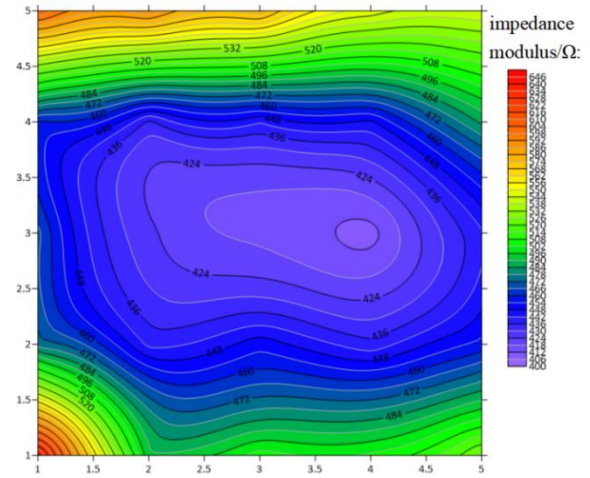


Figure 4. Impedance modulus distribution diagram.

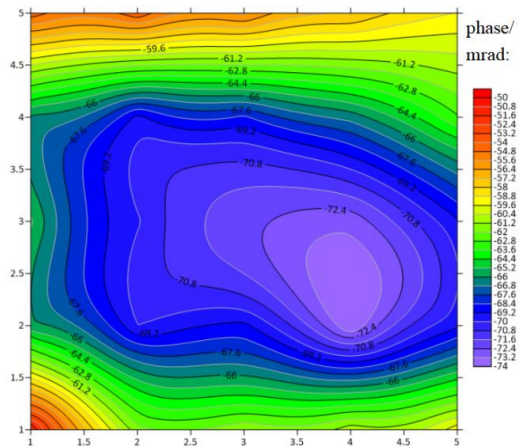


Figure 5. Phase distribution diagram

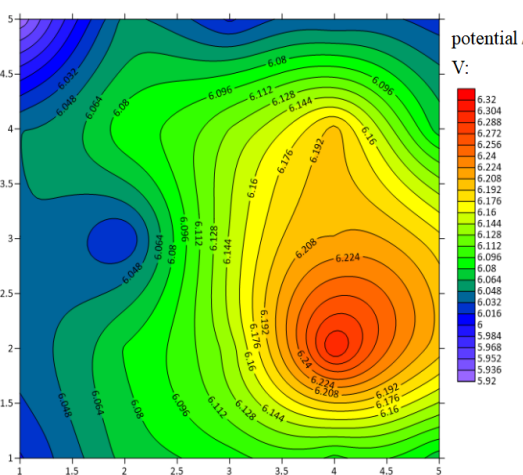


Figure 6. Potential distribution diagram

### 5 Conclusion

The developed leakage monitoring system can effectively collect complex resistivity and potential data. The system

includes command-file processing, data acquisition, and data storage modules. It also includes communication interface modules for data transmission and equipment control to ensure efficient cooperation between various modules. In addition, it has a user interface that allows operators to monitor the system acquisition status and configuration parameters to improve data acquisition efficiency.

The proposed method integrates complex resistivity and potential data to rapidly locate leakage, enabling timely detection of pollutant leakage and supporting environmental risk control in industrial and mining sites. The proposed system provides a practical monitoring tool for early leakage detection and environmental risk control in industrial and mining wastewater facilities.

## 6 Limitations and Prospects

Although this study verifies the feasibility of the system under idealized experimental conditions, such as a single tank and a single known small defect, its engineering performance under practical conditions still requires further evaluation: firstly, the signal superposition caused by multiple leakages in actual working conditions may increase the difficulty of positioning; secondly, the scattering and false abnormal signals caused by the heterogeneity of the structural medium challenge the anti-interference ability of the system; finally, the influence of strong environmental noise on the signal-to-noise ratio and sensitivity of the system is still unknown. Therefore, future research will focus on comprehensive testing under simulated or real complex operating conditions to evaluate and improve the engineering practicality and reliability of the system.

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