Automatic Temperature Measurement of Three Steel Components on Cathodes of 500 kA Cells

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https://doi.org/10.71659/icsoba2025-al048

Abstract

China's electrolytic aluminium production technology uses only pre-baked cells. Three steel temperatures – potshell side, potshell bottom plate and collector bar – are cell operation and control parameters in Chinese cell technologies. The measurement of these temperatures is still made manually. This outdated method requires significant human and material resources, yields low efficiency, endangers the health of operators, and fails to promptly identify potential faults. Therefore, there is an urgent need to implement automatic, continuous, and real-time monitoring of the three steel temperatures. This paper introduces distributed optical fibre temperature sensing technology, which features high sensitivity, stability, reliability, anti-electromagnetic interference, and continuous distributed measurement capabilities, enabling real-time online monitoring of three steel temperatures. This technology can detect temperature changes at any position along the optical fibre, support long-distance and large-scale temperature monitoring, and is of great significance for improving safety and reducing labour intensity.

Keywords: 500 kA aluminium electrolysis cell, Automatic measurement of three steel temperatures, Real-time monitoring, Automatic warning.

1. Introduction

The aluminium electrolysis is a complex physicochemical process, multivariable and nonlinear time-varying process. For such production processes, advanced intelligent control technologies can achieve excellent control results when precise mathematical models are unavailable. The cell operational status directly affects the quality and output of primary aluminium. The three steel temperatures are key cell operation parameters. Accurate measurements of these temperatures are crucial for understanding the cell thermal balance, prevent cell tap-out accidents, and reduce energy consumption. Traditional manual measurement methods for three steel temperatures have many limitations and cannot meet the needs of modern aluminium production for automated control. Upgrading the temperature measurement to automatic measurement effectively improves the digital and intelligent cell control. In this paper, the automatic measurement technology was applied to 500 kA cells.

2. Technical Background

With the development of computer technology, automatic control theory and practice, and advancements in modern large-scale aluminium electrolysis equipment, the automatic control and management have been continuously upgraded. The AI technology has not only reduced manual labour intensity but also promoted the gradual increase in automation of the cells, achieving significant reduction in energy consumption carbon emissions. Modern high amperage cells are complex high temperature electrochemical reactors under the interaction of multiple phases (gas-melt-solid) and multiple fields (electrical, magnetic, thermal, flow, etc.). The complex effects of electrical, magnetic, thermal, and flow fields in electrolysis cells complicate the state of the bath and metal. The enlargement of the cells increases the difficulty of efficient and stable control under critical conditions, placing higher demands on automatic measurement technology. The main control objective during aluminium electrolysis production is to predict alumina concentration and bath temperature, and control alumina feeding and anode-cathode distance (ACD) to ensure the thermal and material balance of the cell.

2.1 Introduction to the Online Temperature Detection System for Three Steel Components of the Cells

This project is an online temperature detection system for three steel components of electrolysis cells in a 500 kA potline. It is necessary to install the mobile measurement equipment to meet the network communication system in the potrooms and select monitoring points in test cells.

2.2 Drawbacks of Traditional Measurement Methods for Electrolysis Cells

Traditional manual temperature measurement of three steel components in the cells mainly uses portable thermometers. It is difficult to standardize operations through manual measurement, since the results depend on the operator's skills and work experience; this makes it difficult to ensure measurement accuracy. Differences in temperature measurement point selection and measurement time among different operators lead to large data dispersion; the frequency of manual measurements is low, so it cannot reflect the dynamic changes of three steel temperatures in real-time. Temperature fluctuations may affect production, but the lag of manual measurements makes it difficult to promptly identify abnormalities and take effective control actions. At the same time, the working environment for manual measurement is harsh, and operators work near high-temperature structures and electrical conductors, posing safety risks. Drawbacks of manual measurements are:

1) Environmental complexity: In the potroom there are high magnetic fields, high temperatures of 950–960 °C in the cells, limited space, and emissions;
2) Lack of data from the cells: Relying on manual inference of the operating status of high-temperature liquids in the cells, lacking real-time temperature data and process information, making it difficult to predict accidents such as cell tap-out;
3) Potline safety risks: Cell tap-out accidents may cause potline open circuit and power outage, resulting in huge economic losses.

3. Online Temperature Measurement System for Three Steel Components of the Cathodes

3.1 Principle of the Measurement System

The automatic temperature measurement technology for three steel components of the cells is based on infrared sensors. The infrared temperature measurement principle utilizes the thermal radiation characteristics of objects. The radiation intensity is related to the object's temperature. High-precision infrared sensors receive infrared rays radiated from the surface of three steel components, and after signal processing and algorithm calculation, the accurate temperature is obtained. At the same time, advanced sensor technologies such as thermocouple sensors and thermal resistance sensors are used to monitor the measurement environment and other related parameters for compensation, improving the accuracy of temperature measurement. To realize automatic measurement of multiple temperature points, a distributed sensor network layout is used, and sensors are installed at key positions of the three steel components.

3.2 Advantages of the Automatic Temperature Measurement

1) Real-time monitoring: 24-hour continuous collection of temperatures at key positions of collector bars, potshell sidewalls and potshell bottoms.
2) Precise warning: Early detection of cell tap-out risks through temperature anomaly identification.
3) Intelligent analysis: Optimization of process conditions using tools such as thermal maps and historical curves.

3.3 System Functional Characteristics

The measurement system includes temperature probes, collection modules, receiver devices, LED displays, client monitoring software, servers, and auxiliary materials. The analysis program includes:

- Functions, such as automatic generation of alarms, manual modification of alarm parameters including alarm baseline values for each temperature measurement point;
- Hierarchical alarm for alarm levels;
- Hierarchical push of alarm data to mobile Apps;
- Communication control module for LED large screens, alarm information display, and voice functions;
- Query and storage of historical and real-time data;
- Display of temperature historical curves and
- Recording of alarm handling processes.

4. Installation of the Online Temperature Measurement System

4.1 Hardware Part

4.1.1 Sensor Unit

The sensor unit is composed of multiple infrared sensors, thermocouple sensors, and thermal resistance sensors. Infrared sensors are responsible for directly measuring the surface temperature of the three steel components, while thermocouple and thermal resistance sensors are used to monitor environmental temperature, humidity, and other factors that may affect measurement accuracy. These sensors have high precision, high stability, and anti-interference capabilities, and can work reliably in the complex electromagnetic and high-temperature environment of the potlines.

4.1.2 Data Acquisition and Transmission Module

This module is responsible for collecting signals from various sensors, performing preliminary processing and analogue-digital conversion. After converting the analogue signals to digital signals, the data is transmitted to the data processing centre through wired or wireless transmission methods. The transmission method can be selected according to on-site actual conditions, such as industrial Ethernet, RS-485 bus, Wi-Fi, etc., to ensure stable and fast data transmission.

4.1.3 Actuator

In systems requiring automatic adjustment, actuators such as electric control valves and motors are installed. Based on the measured temperature data and preset control strategies, the actuator can automatically adjust the operating parameters of related equipment, such as the flow rate of the cooling system to maintain the three-steel component temperature within a predetermined range.

4.1.4 Network Architecture

The installation of the online temperature detection system for three steel components, i.e., the network topology scheme, is shown in Figure 1.

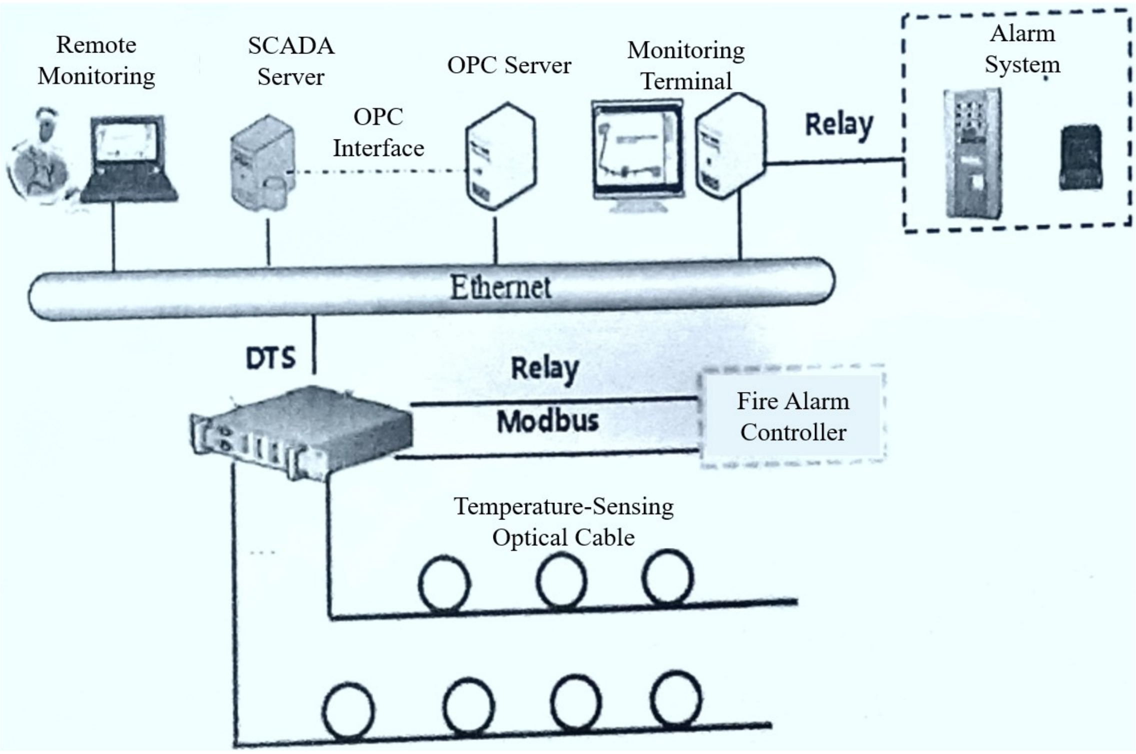

Figure 1. Network topology diagram of the online temperature measurement system.

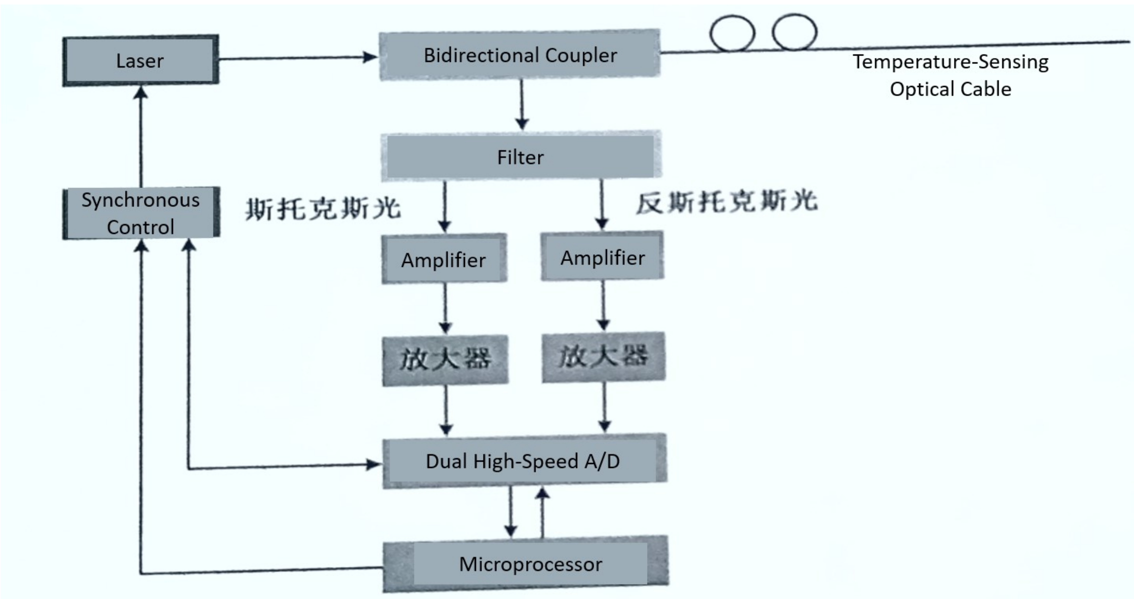

Figure 2. Flow chart of the online temperature measurement system.

4.2 Software Part

4.2.1 Data Processing and Analysis Software

The software performs in-depth processing and analysis of the collected data. Noise interference is removed through filtering algorithms, measurement accuracy is improved using data fusion technology, and temperature change trends are predicted using data analysis models. The software has data storage functions, which can save historical temperature data to provide data support for subsequent production analysis and process optimization.

4.2.2 Monitoring and Alarm Software

Real-time monitoring of temperature changes in three steel components, displaying temperature information in intuitive graphics and data forms on the operation interface. When the temperature exceeds the preset normal range, it immediately issues an audible and visual alarm signal to notify operators to take corrective actions. At the same time, the software has fault diagnosis functions, which can quickly locate and diagnose faults in sensors, transmission lines and other equipment.

5. Construction of the Online Temperature Measurement System in a Potline

5.1 Construction Plan

The online temperature measurement system for monitoring collector bar temperatures was installed on 74 cells in the 500 kA potline. The construction was carried out sequentially. Specifically, all installation procedures in one potroom area were completed first, then all installation personnel moved to the next construction site, leaving technical debugging personnel to debug the system until it operated normally, followed by technical training and acceptance work.

The construction plan content:

1) Formulation of the construction plan and communication of its progress with the client, on the basis of technical contracts and bidding documents
2) Set-up of the project network communication power supply and alarm system to meet the LAN coverage communication arrangement of 8 potroom areas, enabling mobile communication of collection modules and sensors.
3) Installation and wiring of gateway equipment.
4) Installation and wiring of LED display alarm equipment.
5) Installation of temperature measurement sensors and collection modules at the cell bottom.
6) Overall system debugging, alarm system debugging, etc.

5.2 System Installation

Construction of the gateway, alarm equipment power line laying, and temperature measurement equipment for 500 kA cells is shown in Figure 3.

The construction was carried out by cell numbers in the potroom. Data gateways were installed and fixed on the large wall near the window in the cell basement corridor of the potroom for network data exchange. A transfer box was installed next to each gateway for power line or network cable transfer. Each potroom area is equipped with a set of LED display alarm systems for alarming, displaying alarm information points, and reminding workers to perform operation handling. The installation position is near the wall at the entrance of the potroom area on the large operation surface, with a total of 8 sets installed separately in each potroom area.

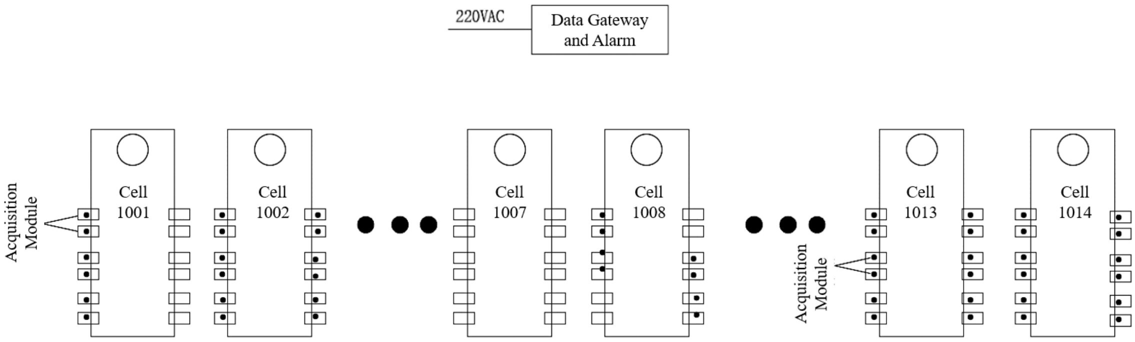

Figure 3. Construction plan of the online temperature measurement system.

The infrared sensors are responsible for directly measuring the surface temperature of the three steel components. On the side shell they are installed at the bath-metal interface level where the temperatures are the highest. On the bottom shell they are installed at one meter from the edge. On collector bars they are installed at the end of collector bars. Along the cells they were installed at 150 positions on side shell, bottom shell and collector bars. Altogether 210 of sensors were installed per cell. All positions are accessible for eventual maintenance or replacement of the sensors. Figures 4–6 show pictures of the installation.

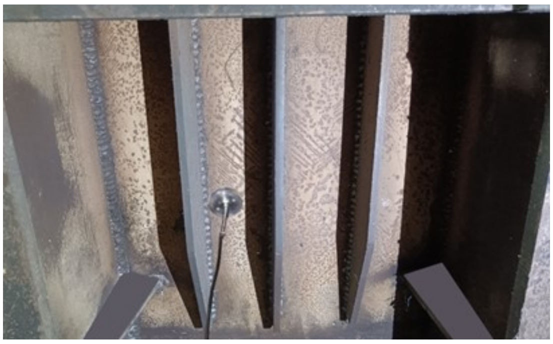

Figure 4. Picture of the sensors installed on the side shell.

Figure 5. Picture of the sensors installed on the bottom shell.

Figure 6. Picture of the sensors installed on the collector bars.

6. Practical Application Results

6.1 Improved Measurement Accuracy and Timeliness

After applying the automatic temperature measurement technology for three steel components of the cathode in a 500 kA potline, the accuracy of temperature measurement significantly improved. Compared with traditional manual measurement, the measurement error of the automatic measurement system is controlled within ±1 °C, effectively reducing data dispersion. At the same time, real-time monitoring of three-steel component temperatures is realized, enabling operators to promptly grasp temperature change dynamics and providing accurate and timely data basis for production control.

6.2 Optimized Cell Operation

Based on the accurate temperature data provided by the automatic measurement system, operators can more precisely adjust the cell process parameters and optimize cell thermal balance. By promptly discovering and handling temperature abnormalities, production accidents caused by temperature problems, such as anode effects and sludge formation, are effectively prevented. The operational stability of the cells is improved, achieving good energy-saving and reducing energy consumption.

6.3 Reduced Labour Intensity and Safety Risks

The application of automatic measurement technology eliminates the need for operators to frequently enter high-temperature and high-magnetic field working areas for manual measurement, reducing labour intensity. At the same time, it reduces direct contact between personnel and high-temperature objects, effectively lowering the probability of safety accidents, improving the working environment, and ensuring the safety of personnel and equipment.

6.4 Comparison Between Manual Measurement Data with Infrared Thermometers and Online Detection System Data.

Table 1 gives the comparison between manual measurements of the cell collector bar temperatures by infrared thermometers and online temperature measurements.

Table 1. 24-hour temperature trend of infrared thermometers and online temperature measurement systems (°C).

Measure Cell No. And Collector Bar	Item	Time/h													
	Collector Bar Temperature/°C	0:00	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00	Average Value/°C	Error/°C
1501A-1	Thermometer Data	295	279	280	294	293	313	287	290	298	288	295	298	292	
	Online Monitoring	301	285	284	298	301	319	291	295	303	295.	298	310	298	5
1502A-1	Thermometer Data	284	281	283	290	292	284	282	283	283	284	284	293	285	
	Online Monitoring	288	286	287	295	297	289	286	286	287	288	288	296	289	4
1503A-1	Thermometer Data	272	279	293	287	293	298	287	292	291	291	282	286	288	
	Online Monitoring	278	284	292	292	298	301	291	297	296	296	285	290	292	4
1504A-1	Thermometer Data	282	282	272	281	281	293	287	281	290	281	284	290	283	
	Online Monitoring	289	288	278	288	286	298	290	284	291	285	288	294	288	5
1505A-1	Thermometer Data	275	273	275	280	283	293	282	285	284	278	282	282	281	
	Online Monitoring	281	276	280	282	287	296	287	282	289	280	286	289	284	3

Table 2 gives the comparison between manual measurements of the potshell bottom temperatures by infrared thermometers and online temperature measurements.

Table 2. 24-hour temperature trend by infrared thermometers and online temperature measurements (°C).

Measure Cell No. and Potshell Bottom	Item	Time													
	Cell Bottom Plate Temperature/°C	0: 00	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00	Average Value/°C	Error/°C
1501A1	Thermometer Data	92	91	87	83	69	78	90	80	81	92	81	83	84	
	Online Monitoring	98	99	94	90	74	80	95	84	89	98	90	86	90	6
1502A1	Thermometer Data	86	88	89	89	67	79	90	83	82	87	86	87	84	
	Online Monitoring	95	99	96	95	79	85	92	88	86	99	85	93	91	7
1503A1	Thermometer Data	86	85	84	87	76	79	91	80	81	83	86	82	83	
	Online Monitoring	93	98	96	93	89	87	94	87	84	88	89	91	91	7
1504A1	Thermometer Data	87	91	92	82	83	82	93	77	84	93	90	91	87	
	Online Monitoring	90	97	96	89	99	91	98	85	89	98	94	96	94	6
1505A1	Thermometer Data	89	92	94	92	78	71	86	78	78	86	81	79	84	
	Online Monitoring	90	98	96	93	93	82	89	84	80	89	90	85	89	5

Table 3 gives the comparison between manual measurements of the potshell side temperatures by infrared thermometers and automatic temperature measurements.

Table 3. 24-hour temperature trend comparison table between infrared thermometers and online temperature measurement systems (°C).

Measure Cell No. and Cooling Vents	Item	Time													
	Cooling Vent Temperature/°C	0: 00	2:00	4:00	6:00	8:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00	Average Value/°C	Error/°C
1501A1	Thermometer Data	377	385	382	378	378	370	388	389	379	373	378	376	379	
	Online Monitoring	382	390	389	382	383	384	395	395	385	380	385	381	386	7
1502A1	Thermometer Data	343	338	338	342	337	341	333	335	383	331	329	337	341	
	Online Monitoring	353	342	341	348	348	352	340	342	391	339	339	344	348	7
1503A1	Thermometer Data	251	286	272	268	286	285	276	287	286	283	282	284	279	
	Online Monitoring	263	291	288	272	289	292	283	294	299	292	289	289	288	9
1504A1	Thermometer Data	262	257	261	240	262	258	261	262	259	256	267	272	260	
	Online Monitoring	269	264	263	269	268	263	269	276	267	257	272	274	268	8
1505A1	Thermometer Data	291	284	284	278	276	289	284	281	260	278	279	294	282	
	Online Monitoring	292	285	289	288	281	293	289	285	286	282	285	291	287	5

From Tables 1, 2, and 3, when comparing manual measurement data with infrared thermometers and online detection system data, the online temperature measurement system for the cell collector bar ends shows an average temperature about 5 °C higher than that of manual infrared thermometers; for potshell bottom plates and sidewalls, the online temperature measurement system data is 5–10 °C higher on average than manual infrared thermometer data. This is because the temperature probes of the online detection system are fixed, installed at the measurement points, so the online measurement data is higher than manual measurement data, and more accurate.

Table 4 summarises the comparison of the two manual and automatic measuring systems.

Table 4. Comparison between traditional manual measurement and online technology.

Measurement Method	Measurement Accuracy	Measurement Frequency	Data Dispersion	Anomaly Warning	Labor Intensity	Safety Risks
Traditional Manual Measurement	Large errors due to inconsistent measurement skills of operators.	Manually set with delayed data.	Large dispersion in data	Delayed data and lagged anomaly warnings	High labor intensity	Many risks, some high risk
Automatic Measurement Technology	Measurement error controlled within ±1 °C, with high precision.	Online detection with automatic data upload.	Stable data with small dispersion.	Automatic data updates and automatic anomaly alarms.	Low labor intensity	Low risk

7. Cost Comparison Between Manual and Online Measuremets

7.1 Investment Cost of the Online System in the Potroom Test Area

The project was implemented on 74 cells in two potroom areas. After full project acceptance, automatic measurement will be gradually extended to the remaining 226 cells. The investment budget includes direct costs of 2.2 million RMB (304 kUSD approx), indirect costs of 100 k RMB (13.8 kUSD approx), labour costs of 100 kRMB, and maintenance costs of 100 kRMB, totalling 2.5 million RMB (346 kUSD approx.). On the premise of achieving advancement, practicality, and reliability, full consideration is given to the project's safety benefits. After project acceptance, unmanned intelligent measurement can be gradually implemented in the remaining cells, maximizing savings in manual inspection costs and fundamentally eliminating cell tap-out accidents.

7.2 Comparison Between Investment Cost in the Online System in Potroom Test Area and Manual Measurement Costs

The aluminium smelter currently employs 27 people for manual measurements, with an average annual cost of approximately 100 kRMB per person (13.8 kUSD/p.y approx.), totalling about 2.7 million RMB annually (374 kUSD/y approx.). Moreover, traditional detection equipment such as infrared thermometers has limited service-life, requiring replacement or repair 3 times per year on average. The annual installation and maintenance cost of the online temperature measurement of three steel components in the potroom test area is 200 kRMB (27.7 kUSD/y approx.) less than that of traditional manual temperature measurement, and the replacement cycle of online monitoring equipment is 5 years.

8. Main Technical Characteristics and Innovations of the Project

Automatic detection technology enables continuous, multi-point online monitoring of cell shell temperatures, automatically generates multi-point temperature curves for each cell shell, and has cell shell temperature threshold alarm functions, which will provide safer operation. The system benefits are:

1) Reliability: The automatic temperature measurement system has self-inspection functions, fault alarm functions, fire cooling priority functions, and environmental temperature monitoring functions. It has high reliability and is easy to maintain.
2) Advancement: The automatic temperature measurement system is set in accordance with fire protection standards. On the premise of meeting practicality and reliability, it uses the most advanced system, which is particularly in line with the latest development trends of computer technology, network communication technology, and digital twin technology, and is quite mature.

3) Safety: The detection part of the optical fibre sensor in the automatic temperature measurement system is passive and intrinsically explosion-proof, unaffected by environmental factors such as weather and dust, and has extremely high safety.
4) Standardization: In addition to complying with national standards, the design of the automatic temperature measurement system also meets the functional requirements of the system, achieving structuring and standardization, which can comprehensively reflect the current advanced technical level.
5) Economy: On the premise of achieving advancement, practicality, and reliability, full consideration is given to the economic benefits of the system, making its performance-price ratio optimal among similar systems and conditions.

9. Conclusions

The online monitoring technology for temperature measurement of three steel components of the cathode, is advanced, practical, and reliable and safer than manual measurements. After acceptance of the project on 74 test cells, unmanned intelligent measurement system can be gradually implemented in the rest of the potline to maximize savings compared to manual measurement costs. The automatic system practically eliminates cell tap-out accidents. After technology promotion, an automated temperature measurement system suitable for large-scale electrolysis cells can be developed to improve the company's digital and intelligent level, meeting both the company's production business process needs and maximizing benefits.

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