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Research on methods for prediction, evaluation, and compensation of the stability of integrated circuit test equipment

Zhan Wenfa, Zheng Jiangyun
Anqing Normal University

TestConX中国™ China

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安慶師範大學
ANQING NORMAL UNIVERSITY

Primary Coverage

- Research Background and Significance
- Research objectives and methods
- Research process and analysis
- Research conclusions and prospects

The Deficiencies of Current Research Status

1、Traditional IC test equipment stability prediction methods have defects and insufficient identification of abnormal data. At present, stability prediction research has significant shortcomings in long-term data accumulation and dynamic coupling analysis.

2、The traditional offline maintenance mode leads to low testing efficiency of IC test equipment, which seriously affects production capacity. The online evaluation method for IC test equipment is still in the exploratory stage, lacking a systematic evaluation framework.

3、The unstable IC test equipment noise interferes with the test results, reduces the test accuracy, and affects the accuracy of chip performance evaluation. In practical application, real-time compensation technology still has the problem of trade-off between accuracy and efficiency.

Theoretical significance

Enrich the theoretical system of IC test equipment stability research, and provide new ideas and methods for related research.

Realistic meaning

Improve chip production efficiency and quality, reduce production costs, enhance the competitiveness of the industry market.

Research technique

1、A method for predicting the stability of integrated circuit test equipment by using the upper boundary value of normal distribution

2、SWAQ integrated analysis model for online stability evaluation of integrated circuit test equipment

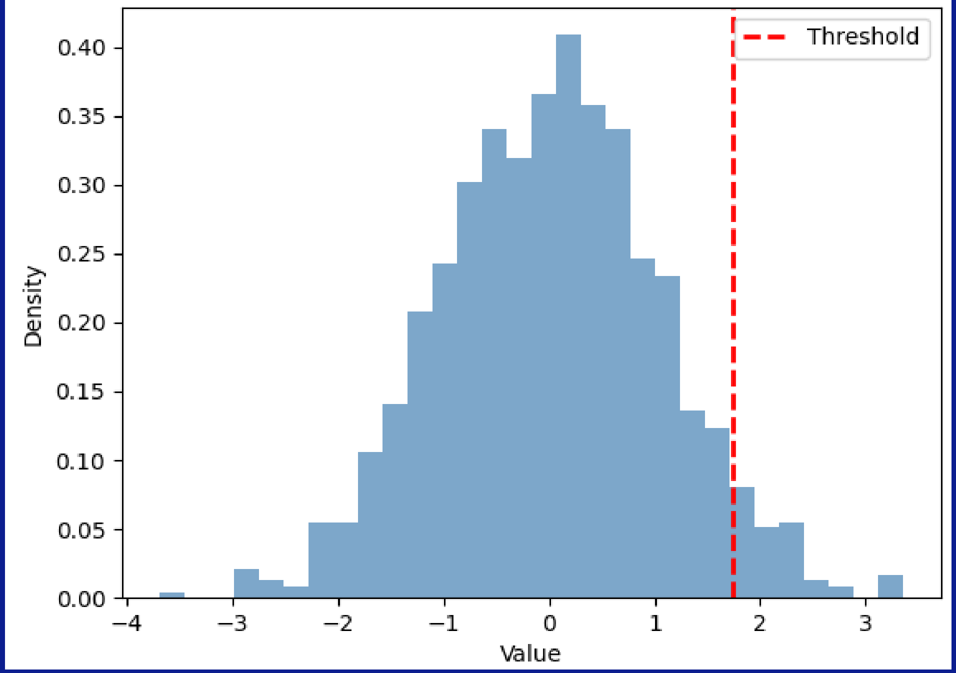
3、Real-time compensation method for chip test results based on PSO-KF algorithm

Research process and analysis

1. A method for predicting the stability of integrated circuit test equipment by using the upper boundary value of normal distribution.

The K-Medoids clustering algorithm is employed to classify and analyze the sample data.

The stability judgment threshold of integrated circuit test equipment is set by comparing the accuracy of the upper boundary value of the normal distribution under different confidence levels. The threshold is used to detect alarm test data.



Accuracy Comparison Results

The accuracy comparison in the table shows that the accuracy of the upper bound of normal distribution with 95% confidence level is generally higher than that of the upper bound of normal distribution with 99% confidence level.

Taken together, we found that 95% confidence achieved a better balance between accuracy and sensitivity.

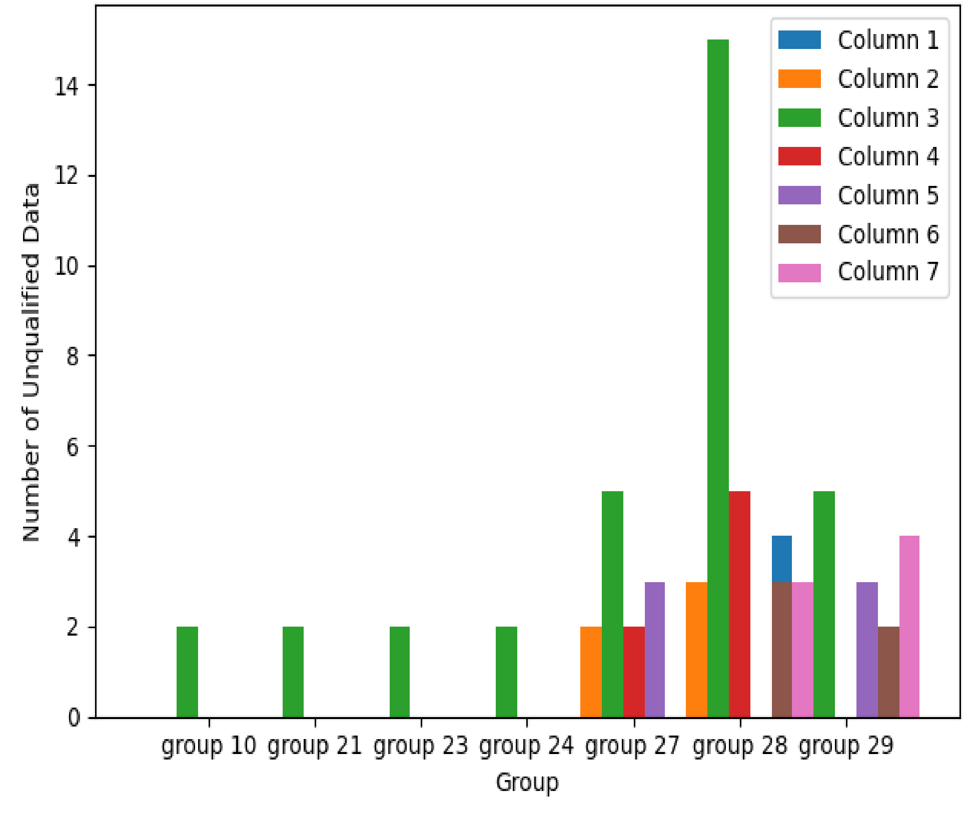
表 2.2 95%和 99%置信度下正态分布上侧界值准确度比较结果

Table 2.2 Results of comparison of accuracy of upper side bounds of normal distribution at 95% and 99% confidence levels

参数名称	置信度/%	不合格数据所在组号	不合格数据数量	准确率/百分比
Conti_AC2	95	29	4	96
	99	29	4	96
Conti_AC1	95	27/28	2/3	97.5
	99	28	3	97
Conti_VDD18V	95	10/21/23/24/27/28/29	2/2/2/2/5/15/5	95.3
	99	27/28/29	5/15/5	91.7
Conti_RECT	95	27/28	2/5	96.5
	99	28	5	95
Conti_COMM2	95	27/29	3/3	97
	99	27/29	3/3	97
Conti_CLMP1	95	28/29	3/2	97.5
	99	28	3	97
Conti_VDD5V	95	28/29	3/4	96.5
	99	28/29	3/4	96.5

Feasibility validation results

Among the 7 columns of collected test data, most of the unqualified data that output alarm information and exceed the set threshold are located in the 27th group to 29th group. When the machine detects IC from 2700 to 2900, the test equipment begins to have stability problems, and the machine needs to be tested and adjusted for stability to ensure the stability of the machine.



Research process and analysis

2. SWAQ integrated analysis model for online stability evaluation of integrated circuit test equipment. SWAQ comes from the integration of three key quantitative analysis methods: Spearman Rank Correlation Coefficient, SRCC, Weighted Average Method, WAM, Quadrants Chart, QC

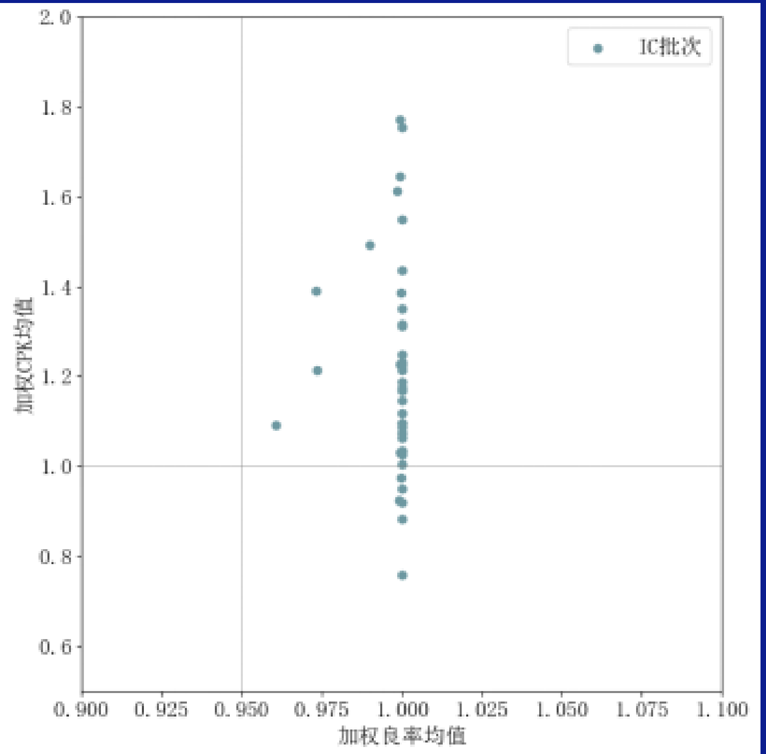
Collect equipment operation data, including test results and equipment parameters. Use SRCCA to analyze correlations between test items and calculate their weights.

The weighted average yield and weighted CPK mean are calculated using the weighting method to comprehensively evaluate equipment stability.

QC visually displays the quality and stability of each batch, providing reference for equipment maintenance and optimization.

Ablation results

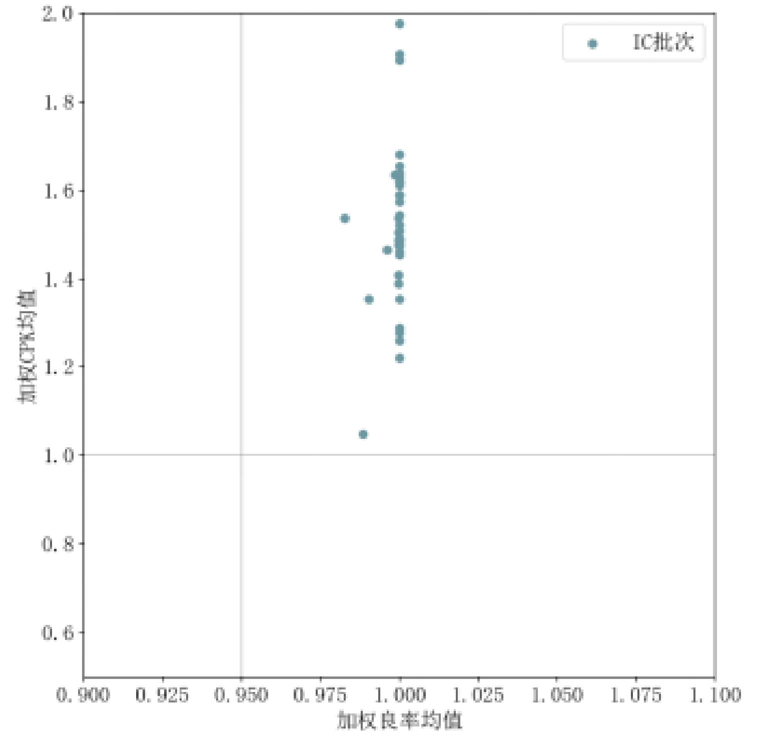
Figure (a) displays the real-time evaluation of each batch of ICs in the four-quadrant plot using the complete SWAQ model, demonstrating that the yield and CPK values of each batch ICs do not significantly deviate from the overall distribution, proving good equipment stability. Any outliers will be visually highlighted in the plot, helping test engineers promptly identify and address potential issues.



(a) SWAQ 模型结果

Ablation results

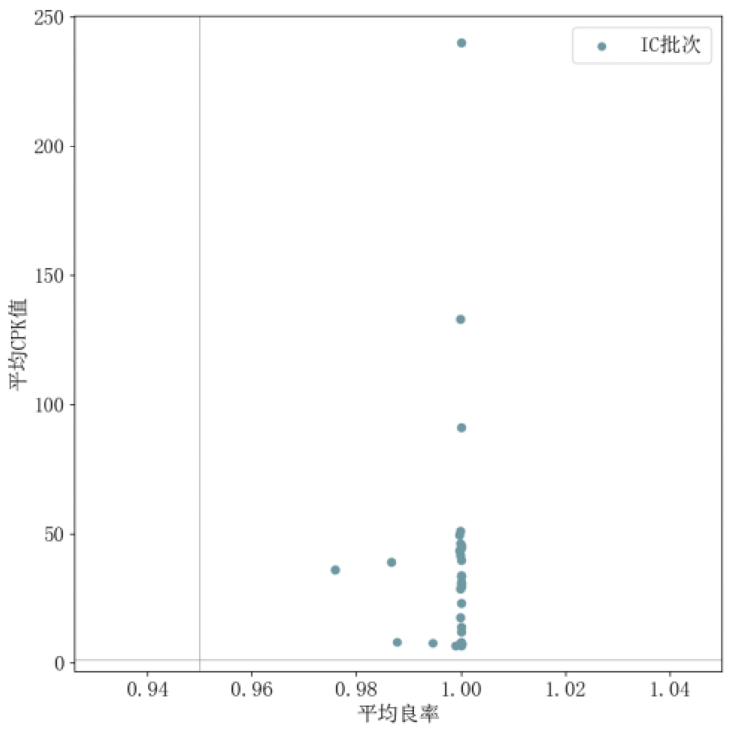
Figure (b) shows the ablative SRCCA analysis model, where QC data points are notably clustered with high weighted CPK values and low variability. Due to the absence of redundant information filtering in the test items, the model fails to distinguish batch-to-batch stability differences, resulting in overly uniform evaluation outcomes that may mask underlying issues.



(b) WAQ 模型结果（消融 SRCCA）

Ablation results

Figure (c) demonstrates the QC of the WAM analysis model after weight removal. The CPK distribution becomes abnormally wide, with some batches exceeding 100. The simple averaging method amplifies the impact of extreme test items, distorting the evaluation and failing to reflect the true contribution of each test item, thereby reducing the reliability of stability assessment.



(c) SAQ 模型结果（消融 WAM）

Comparison of Methods

The SWAQ model supports real-time evaluation, enabling continuous monitoring of device stability during operation, timely detection of issues, and prompt corrective actions.

The SWAQ models innovative approach to weight allocation makes its stability assessment more accurate than other methods, as conventional approaches often neglect weight distribution across test items, potentially leading to incomplete or inaccurate analysis results.

表 3.1 本章方法与其他三种稳定性评估方法比较

Table 3.1 Comparison of the methodology in this chapter with three other stability assessment methods

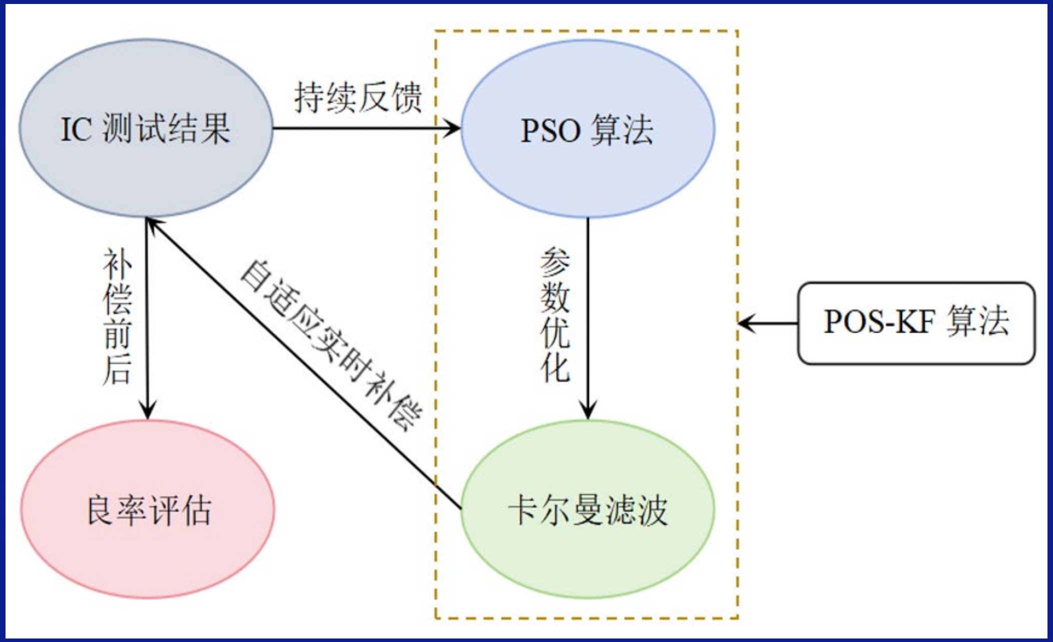
方法	方法 1[77]	方法 2[78]	方法 3[79]	本文方法
评估对象	钙钛矿太阳能电池	电力系统暂态稳定	地基变形	IC 测试设备稳定性
是否实时评估	×	√	×	√
是否考虑权重	×	×	×	√
响应时间	长	瞬间	长	极短
维护周期	定期维护	实时评估监控	长期监测	实时稳定性评估触发的按需维护

Research Process and Analysis

3.Real-time compensation method for chip test results based on PSO-KF algorithm.

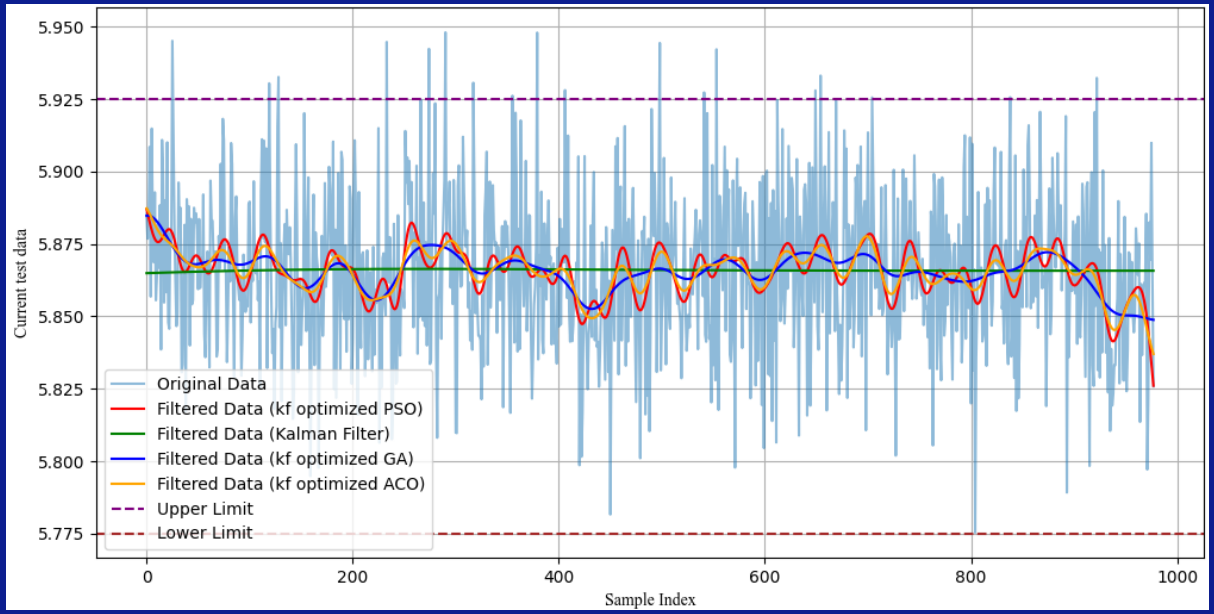
PSO-KF is The abbreviation for Particle Swarm Optimization (PSO) Algorithm, Kalman filter(KF)

By introducing the PSO optimization algorithm, the noise parameters in KF can be dynamically adjusted to automatically adapt to the noise level during the test process and run in real time during data acquisition.



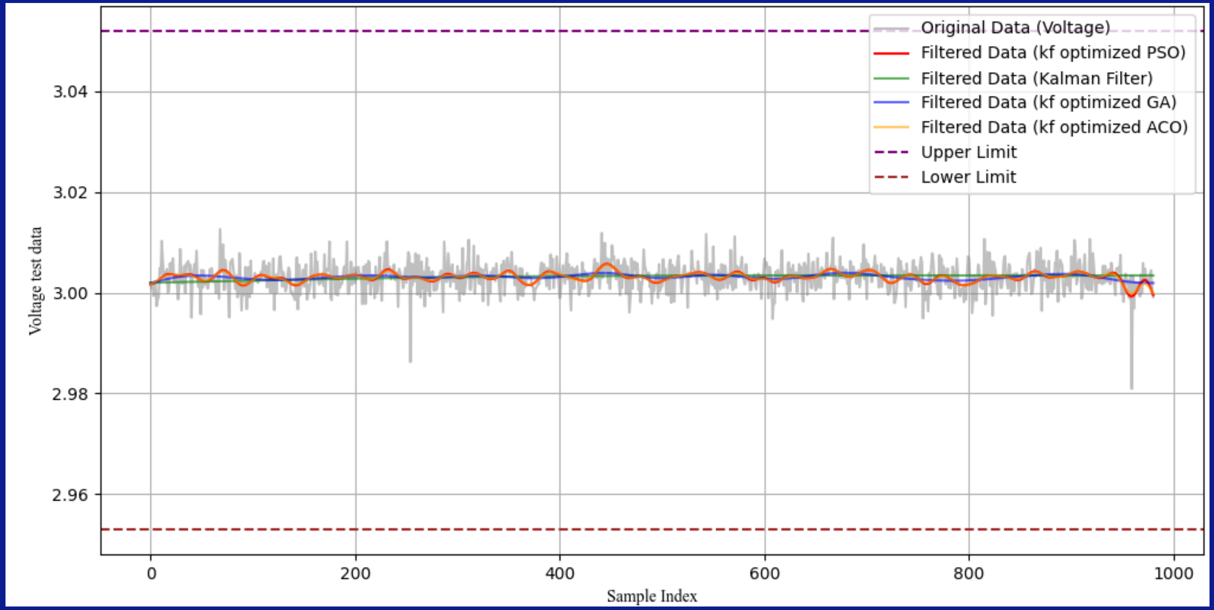
Compensation effect comparison

The figure demonstrates the compensation effect of current test data. The filtered data after PSO optimization achieves optimal smoothing, significantly reducing noise and maintaining stable current values.



Compensation effect comparison

The compensation effect of voltage test data is shown in the figure on the right. The KF data (red curve) after PSO optimization is smoother in comparison, which can effectively suppress noise, reduce data fluctuations, and ensure the stability of test results.



Compare different optimized KFs

The table shows the mean square error (MSE) and variance results of different optimized KFs under current (I) and voltage (U) tests. The comprehensive score in current test is 0.772430, and the comprehensive score in voltage test is 1.746343, both higher than other optimized algorithms.

不同优化情况下的 KF	测试项	MSE	方差	综合评分
仅 KF	电流	0.000746	8.642568	1.000086
	电压	8.636378	1.681269	1.194533
经 GA 优化的 KF	电流	0.000710	3.633732	0.420528
	电压	8.487595	6.093453	1.687824
经 ACO 优化的 KF	电流	0.000692	5.042970	0.583584
	电压	7.909138	5.383447	1.538692
经 PSO 优化的 KF	电流	0.000673	6.675107	0.772430
	电压	7.648095	7.439309	1.746343

A higher overall score indicates better performance of PSO-optimized KF, enabling more accurate and stable data processing and compensation.

Compare compensation yield before and after

良率	电流测试良率	电压测试良率
补偿前	98.365%	99.598%
补偿后	99.754%	99.983%
提升值	1.389%	0.385%

The table compares yield rates before and after compensation using the PSO-KF algorithm. For the current test item, the pre-compensation yield was 98.365%, which improved to 99.754% after applying the PSO-KF algorithm, representing a 1.389% increase. In the voltage test item, the pre-compensation yield was 99.598%, rising by 0.385% to 99.983% post-compensation.

This improvement demonstrates that the compensation process effectively reduces measurement errors, preventing products that were already qualified from being misclassified as non-conforming due to equipment instability.

Research Conclusion 1

The prediction method takes the upper boundary value of normal distribution as the threshold of certainty to carry out stability analysis, which can accurately and long-term judge the abnormal situation in the operation of equipment, and realize the reasonable prediction of the long-term operation situation of IC test equipment.

Research Conclusion 2

The SWAQ evaluation model demonstrates significant advantages in real-time assessment, weight allocation, response time, and maintenance cycles. It effectively identifies redundant test items and allocates weights appropriately, accurately differentiates performance variations between batches, and transforms routine maintenance into on-demand servicing. This approach achieves simultaneous improvements in evaluation efficiency and accuracy while enhancing the reliability of testing equipment.

Research Conclusion 3

The PSO-KF compensation method effectively mitigates interference from unstable test equipment, outperforming conventional optimization Kalman filters in stability and noise resistance. Post-compensation, the yield rates for current and voltage measurements improved by 1.389% and 0.385% respectively, significantly enhancing the reliability and quality of IC testing results.

Future Expectations

Stability forecast

With the emergence of new 3D stacked chips, how to improve the processing efficiency and level of prediction methods for new test data is the focus of optimization.

Stability assessment

As test requirements become increasingly diversified and complex, it is necessary to consider how the model can adapt to the test environment of different types of IC.

Test result compensation

In large-scale test application scenarios, the adaptive ability of compensation algorithm needs to be strengthened in the increasingly complex and unstable situation.