Research on Failure Modes and Impact Analysis of Key Electronic Components

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Abstract. Analyze the failure mode of electronic components, find the type of stress that causes the failure of the energy meter, trace the key components that cause the fault, and complete the failure mode and impact analysis of key electronic components through failure detection means and failure analysis experiments. In order to develop a reliable product, it is necessary to understand the potential failure mechanism of the product. Modeling to describe the relevant failure modes can promote the development of product design principles. The research results of failure mechanism are not only conducive to improving the reliability manufacturing level of domestic electric energy meter, but also can save the maintenance and transformation cost of electric energy meter, and have very important practical significance for the construction of smart grid.

1. Introduction

The electric energy meter is responsible for the important task of metering and charging, and it continues to operate stably. Due to the complex on-site environment, most electric energy meters are subject to long-term severe temperature and humidity changes, lightning, power grid fluctuations and electromagnetic interference. Under the influence of external environment and load factors, the failure of the energy meter is inevitable, which not only brings great maintenance costs. Even the economic disputes and compensation for electricity use have produced extremely bad consequences.

This paper focuses on the environmental characteristics area, load characteristics and damage mechanism of electric energy meter components. From the theoretical research and statistical analysis of fault data, we find the cause of failure and the concentrated area, and analyze some common faults of electric energy meter by combining work practice. The specific causes of these faults are discussed, and corresponding improvement suggestions are proposed for related reasons, thus providing data and theoretical support for the design improvement of the energy meter.

2. Failure mode analysis of electronic components

In order to better analyze the internal mechanism of the fault phenomenon, more in-depth research and discussion are needed to analyze the failure mechanism from the perspective of physics. First, look for the type of stress that can cause the meter to fail.

Stress is the internal cause of component failure, and is the initial input of the process of laboratory recurrence failure. Grasping and utilizing various stresses and conditions that cause failure, effectively
controlling experimental variables by artificially increasing the type of stress required. It provides a shortcut for research and analysis of component failure under laboratory conditions.

The classification of failure mechanisms is based on the type of stress that triggers failure: mechanical, thermal, electrical, pollution, and corrosion.

1. Mechanical failure refers to failure caused by elastic deformation and plastic deformation, warpage, brittle fracture and deformation fracture, fatigue fracture initiation and propagation, creep and creep fracture.

2. Thermal failure is the failure that occurs when the component is heated above its critical temperature, such as the glass transition temperature, melting point, or flash point.

3. Electrical stress failure refers to failure caused by electrostatic discharge, dielectric breakdown, click through, hot electron injection, surface trapping and body trapping, surface breakdown, and the like.

4. Pollution failure means that the pollutant carries conductive ions and introduces additional conductive channels. Pollution causes structural and quality changes to change the nature of the contaminated site.

5. Corrosion failure means that the pollution carries corrosive ions and develops into corrosion.

The root cause of the failure of the energy meter is component failure, some component failures are caused by defects in the production process, some are caused by insufficient design margin, and some are caused by improper installation and installation, and the causes of component failure are complicated.

![Classification diagram of failure mechanism of electronic components.](image)

**Figure 1.** Classification diagram of failure mechanism of electronic components.

Designers need to find the source of stress that causes failure through the actual working environment of the component, including the electrical environment, temperature and humidity environment, and load environment. Through the damage detection process of components, the damage process of components is also explored to find the basis for component failure.
3. Electronic component failure analysis method

3.1. Failure detection means

For a faulty energy meter, finding the type of fault and tracing the key components that caused the fault is only the first step. How to damage the key components of the fault, detect the characteristics and methods of component damage through technical means, find the root cause of the damage of key components, and provide reference and guidance for future design, which is the fundamental driving force for the improvement of electric energy meter.

After the fault diagnosis, it is necessary to go through the circuit design principle to check the component group that caused the fault and find the core problem point. For the analysis of critical component damage, observation alone is not enough, because most component damage is not accompanied by obvious damage phenomena, such as resistance resistance drift, capacitor cracking, diode reverse breakdown, etc., especially for some components. For damage, it is necessary to use instruments to detect and analyze. The commonly used detection and analysis methods for component failure include acoustic microscope analysis, optical microscope analysis technology, infrared analysis technology, liquid crystal hot spot detection technology, and optical radiation microscopic analysis technology.

3.2. Failure analysis experiment

The failure verification experiment simulates the field work and environmental conditions, and repeatedly applies various working modes and environmental stresses to the tested components in a certain cycle order according to a certain time ratio, and actively strengthens the respective failure influencing factors. Inspire component defects, accelerate the process of faults, locate corresponding defects in a short period of time, identify the main external factors that cause product failure, and then propose improvement measures through failure mechanism analysis to effectively shorten high-quality products. Development cycle.

The purpose of the component failure test is to determine the type of stress that causes component failure and the worst environmental impact factors for normal components that meet the requirements of the technical documentation. Before the experiment, it is necessary to eliminate the components that are inherently defective, in order to ensure that the component failure after the experiment is not caused by the inherent defects of the components.

Corresponding to the type of stress, failure verification experiments are divided into mechanical, thermal, electrical, pollution and corrosion experiments. The failure verification experiments often performed on the whole machine and components mainly include printed board bending test, double 85 experiment, thermal shock test, long-term power-on type test and so on.

4. Key electronic components FMEA analysis

There are many types of components and models used in electric energy meters, but the energy meters of different manufacturers basically use component materials of similar types. Now, the common failure modes and mechanisms of resistance originals are taken as examples, and the key to single-phase electric energy meters. The main mode and mechanism of the material were analyzed.

The 0603 chip resistor reports a batch fault in the functional test after the meter is assembled. After the positioning, it is found that the resistance of the resistor is increased and unstable. The samples collected for failure analysis are shown in Table 1.

| Serial number | status                                         | Quantity | Numbering       |
|---------------|-----------------------------------------------|----------|-----------------|
| 1             | Unused product                                 | 5        | G1#–G5#         |
| 2             | Defective product that has been welded from the board | 5        | F1#–F5#        |
| 3             | Failed goods on board                          | 5        | F6#–F10#       |
1) Appearance observation
The sample was visually inspected and no obvious abnormality was observed in the appearance of the sample.

2) X-RAY observation
X-ray observation of all samples showed no obvious abnormalities such as voids and disconnection of the surface electrode. The typical morphology is shown in Fig. 2.

![Typical X-RAY morphology of the sample.](image)

(a) Good product (G1#)  (b) Soldering defective products (F1#)  (c) On-board failure (F8#)

3) Electrical parameter test
All sample resistance values (R) were tested and the test results are shown in Table 2.

| Numbering | G1#     | G2#     | G3#     | G4#     | G5#     |
|-----------|---------|---------|---------|---------|---------|
| R (kΩ)    | 4.7531  | 4.7705  | 4.7652  | 4.7766  | 4.7591  |
| Numbering | F1#     | F2#     | F3#     | F4#     | F5#     |
| R (kΩ)    | F1#     | F2#     | F3#     | F4#     | F5#     |
| the first time | 5.2068  | 5.3534  | 4.9583  | 5.5157  | open circuit |
| the second time | 5.2367  | 5.2109  | 4.9658  | 5.5834  | open circuit |
| Numbering | F6#     | F7#     | F8#     | F9#     | F10#    |
| R (kΩ)    | F6#     | F7#     | F8#     | F9#     | F10#    |
| the first time | 4.7561  | 12.8371 | 39.2342 | 4.7601  | 5.5531  |
| the second time | 4.7567  | 12.8123 | 5.0925  | 4.7609  | 5.5724  |
| other     | The first and second test interval is about 16 hours |

It can be seen from the table that the resistance values of the good products are within the qualified range; the resistance values of the failed products that have been soldered are greater than the acceptance criteria; the resistance values of the samples F7#, F8#, F10# on the board are greater than the qualified values. The criterion, and the resistance values of the two test samples before and after F8 are relatively large, while the resistance values of the other two samples F6# and F9# are within the qualification criteria.

4) Metallographic section observation
Metallographic sections were observed on G1#, F1#, F5#, and F7# samples.

![Typical morphology during good grinding (G1#).](image)

(a) Full view  (b) Magnified shape
**Figure 4.** Typical morphology of the failed product grinding process (F1#).

**Figure 5.** Typical morphology of the failed product grinding process (F7#).

**Figure 6.** Typical morphology of the failed product grinding process (F5#)

**Figure 7.** F1# the appearance of the sample surface electrode deviates from the normal position.
The typical metallographic slice morphology of the good product is shown in Fig. 3. No obvious abnormality is observed: the surface electrode extends to the end of the ceramic, and the Ni and Sn layers can be seen at the terminal electrode. The F1#, F5#, and F7# samples can be seen: in addition to the Ni layer and the Sn layer, there is an Ag layer on the side electrode of the surface electrode, and F1# and F7# can also be used. See the disconnection between the Ag layer and the surface electrode inside the terminal electrode, the morphology is shown in Fig. 4 and Fig. 5, and the disconnection position is always observed during the grinding process; and the F5# sample has no obvious abnormality observed. See Figure 6. The F1# sample can see that the surface electrode has a significant offset, that is, the one side electrode is very close to the corresponding end, and the other end electrode is far from the corresponding end, and the appearance is shown in Fig. 7.

5) SEM observation

SEM observation of the F5# sample.

![Figure 8. F5# sample surface electrode has no abnormal morphology.](image1)

![Figure 9. Good connection between F5# sample surface electrode and resistive film.](image2)

![Figure 10. Connection morphology between sample Ag layer and surface electrode.](image3)

No abnormalities were observed in the F5# sample surface electrode, and the morphology is shown in Fig. 8; no abnormality was observed in the connection between the surface electrode and the resistive film, and the morphology is shown in Fig. 9. However, there is a significant abnormality in the connection between the Ag layer and the surface electrode between the terminal electrodes: the organic material is connected between the Ag layer and the surface electrode, and the morphology of the Ag layer connected to the surface electrode is not seen, as shown in FIG.

At the same time, after G1#, F1#, and F5# were over-etched, the connection state between the surface electrode and the terminal electrode was measured, and it was found that G1# and F1# were
well connected; and the connection between the surface electrode and the terminal electrode of the F5# sample was unstable. The state of the resistance varies from tens of ohms to tens of thousands of ohms.

5. Conclusion
In the actual application, the intelligent electric energy meter will malfunction and even expose the batch quality problem. Therefore, in addition to the quality inspection of the smart electric energy meter, the failure measurement analysis of the smart electric energy meter becomes an important and long-term work.

Identify the various failure mechanisms triggered by the stresses in the life cycle of the system. In the development stage of the energy meter, correct the errors in the development in time, thus shortening the development cycle; in the production, testing and use phase of the energy meter, as soon as possible The cause of the failure, thus determining the responsible party for failure; through the failure analysis results, manufacturers can improve the design and process of components, users can improve the design of the board, change the supplier of the device.

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