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Using thermal image matter-element to design a circuit board fault diagnosis system

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ABSTRACT

This paper presents a thermal image matter-element used to design a circuit board signal fault diagnosis system. When a circuit element presents faults the temperature distribution will skew. Therefore, extension theory is used to build several kinds of thermal image matter-element models with fault circuits. According to the matter-element and correlation function, the fault type in the testing circuit is detected by analyzing the correlation degree between the typical fault models and test circuit boards. This new method can attain fast fault determination and reduced manpower.

1. Introduction

In the recent years, both technology and the economy have grown fast. Most electronic products have electronic power circuits. However, these circuits contain several features such as high speed, high stability and small volume. As a consequence, several techniques have been presented in the literatures (Bandler & Salama, 1985; Liu, 1991) not widely accepted for analog circuits fault diagnosis.

Electronic products are widely used. Sometimes defective electronic products are produced during manufacturing. Determining if all products are normal is difficult. Electronic circuit failures are dangerous. So we cannot ignore this.

In the past, expensive machine testing circuits have been used to determine if the circuit is normal or not. However, the reason for the fault cannot be identified through testing. Most electronic power circuits are included in large electrical power and high power systems. Fault diagnosis of analog circuits is a difficult problem. This difficulty is due to several reasons (El-Gamal, 1990; El-Gamal & Abdulghafour, 2003):

1. The inaccuracy in circuit measurements in conjunction with the inability to measure current without breaking the circuit connections.
2. The tolerance in circuit elements often complicates the fault diagnosis process.
3. The limited accessibility to circuit nodes, especially in modern integrated circuits.
4. The lack of good fault models because analog circuits have a continuum of possible faults.

A fault diagnosis procedure that is capable of saving manpower, reducing danger to people, achieves fast and high efficiency and saves failure diagnosis costs. We use a heat system analyzing machine to observe the heat spread condition and match extension theory (ET) to analyze the fault-point. This approach contacts the circuit boards to reduce the destructive factor in testing. The fault diagnosis method using thermal imaging based on extension engineering for circuit boards has the following advantages: (1) Does not contact the circuit broads, reducing the damage from human behavior. (2) The speed is fast and time saving. (3) Reduces the fault occurrence rate using an instant detection of overheated electronic components (Yang & Tsai, 2000).

In recent years, extension theory (ET) has proposed practical applications on different applications for fault diagnosis (Chou & Liu, 2006; Wang, 2004; Wang & Chen, 2001). Therefore, this paper proposed a new method using the extension theory and develops a fault diagnosis scheme for soft fault of analog circuit.

2. Review of extension theory

In the standard set, an element either belongs to or, so the range of the standard set is {0, 1}, which can be used to solve a two-value problem. In contrast to the standard set, the fuzzy set allows for the description of concepts in which the boundary is not explicit. It concerns whether an element belongs to the set and also to what degree it belongs. The fuzzy set range is [0, 1]. The extension set extends the fuzzy set from [0, 1] to $(-\infty, \infty)$. As a result, it allows us to define a set that includes any data in the domain. Extension theory tries to solve the incompatibility or contradiction problems by transforming the matter element (Huang, Yang, & Huang, 1997). The comparisons of the standard sets, fuzzy sets and extension sets

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are shown in Table 1. Some definitions of extension theory are introduced in the next section.

2.1. Matter-element theory

2.1.1. Definition of matter-element

Defining the name of matter as N, the characteristics of the matter as c, and the value of c as v, a matter-element in extension theory can be described as follows:

$$R = (N, c, v) \tag{1}$$

where N, c, and v were called the three fundamental elements of the matter-element. For example, R = (Wang, Weight, 75 kg) can be used to state that Wang's weight is 75 kg. If the value of the characteristic has a classical domain or a range, then we define the matter-element for the classical domain as follows:

$$R = (N, c, v) = (N, c, \langle v^L, v^U \rangle) \tag{2}$$

where v^L and v^U are the lower bound and upper bound of a classical domain.

2.1.2. Multi-dimensional matter-element

Assuming $R = (N, c, v)$ to be a multidimensional matter-element, $c = [c_1, c_2, \ldots, c_n]$ to be a characteristic vector and $v = [v_1, v_2, \ldots, v_n]$ to be a value vector of c, then a multidimensional matter-dement is defined as:

$$R = \begin{bmatrix} N & c_1 & v_1 \\ & c_2 & v_2 \\ & \vdots & \vdots \\ & c_n & v_n \end{bmatrix} = \begin{bmatrix} R_1 \\ R_2 \\ \vdots \\ R_n \end{bmatrix} \tag{3}$$

where $R_i = (N, c_i, v_i)$, $(i = 1, 2, \ldots, n)$ is defined as the sub-matter-element of R.

2.2. Extension set theory

2.2.1. Definition of extension set

Let U be the universe of discourse, then an extension set $\widetilde{A}$ on U is defined as a set of ordered pairs as follows:

$$\widetilde{A} = \{(x, y) | x \in U, y = K(x) \in (-\infty, \infty)\} \tag{4}$$

where $y = K(x)$ is called the correlation function for extension set $\widetilde{A}$. The $K(x)$ maps each element of U to a membership grade between $-\infty$ and ∞. The higher the degree, the more the elements belong to the set. In a special condition, when $0 \leqslant K(x) \leqslant 1$, it corresponds to a normal fuzzy set. $K(x) \leqslant 1$ implies that the element x has no chance to belong to the set. When $-1 < K(x) < 0$, it is called an extension domain, which means that the element x still has a chance to become part of the set.

Table 1
Three different sorts of mathematical sets.

Compared item	Standard set	Fuzzy set	Extension set
Research objects	Data variables	Linguistic variables	Contradictory problems
Model	Mathematics model	Fuzzy mathematics model	Matter-element model
Descriptive function	Transfer function	Membership function	Correlation function
Descriptive property	Precision	Ambiguity	Extension
Range of set	$C_A(x) \in (0, 1)$	$\mu_A(x) \in [0, 1]$	$K_A(x) \in (-\infty, \infty)$

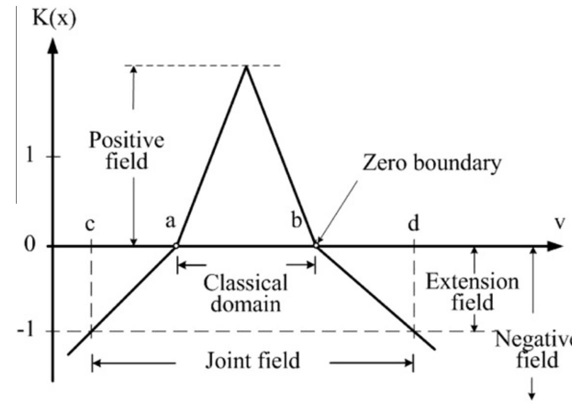

Fig. 1. The proposed extended relation function.

2.2.2. Definition of correlation function

The correlation functions have many forms dependent on application. If we set $X_o = \langle a, b \rangle$ and $X = \langle c, d \rangle$ are two intervals in the real number field, and $X_o \in X$, then the correlation function in the extension theory can be defined as follows:

$$K(x) = \frac{\rho(x, X_o)}{D(x, X_o, X)} \tag{5}$$

where

$$D(x, X_o, X) = \begin{cases} \rho(x, X) - \rho(x, X_o) & x \notin X_o \\ -\rho(x, X) & x \in X_o \end{cases} \tag{6}$$

$$\rho(x, X_o) = \left| x - \frac{a+b}{2} \right| - \frac{b-a}{2}, \quad \rho(x, X) = \left| x - \frac{c+d}{2} \right| - \frac{d-c}{2} \tag{7}$$

The correlation function can be used to calculate the membership grade between x and X_o as shown in Fig. 1 when $K(x) \geqslant 0$. It indicates the degrees to which x belongs to X_o. When $K(x) < 0$ it describes the degree to which x does not belong to X_o. When $-1 < K(x) < 0$, it is called the extension domain, which means that the element x still has a chance to become part of the set if conditions change.

3. Experiment circuit and method

This study primarily used thermal image to judge faults for circuit boards, so it needed electronic devices which can get the thermal images when circuit boards were operating, it also can link with the computer. In addition, this research method needs computer software, which can build the matter-element model of the thermal image and for calculating the extension distance and setting the weight values, then calculating the correlation function, finally to analyze the circuit boards that belong to breakdown reasons.

3.1. Experiment circuit board

In order to test the proposed technique the boost converter circuit in Fig. 2 was considered where single faults at component level are taken into account because such a circuit generates heat fast and is simple to make. It's also includes the major electronic element and the various temperature distribution situations on the element that are easy to observe. For these reasons a boost converter circuit is utilized to make several kinds of faults.

The real boost converter circuit in Fig. 3 is a power converter with an output DC voltage greater than its input DC voltage. The key principle that drives the boost converter is the tendency of

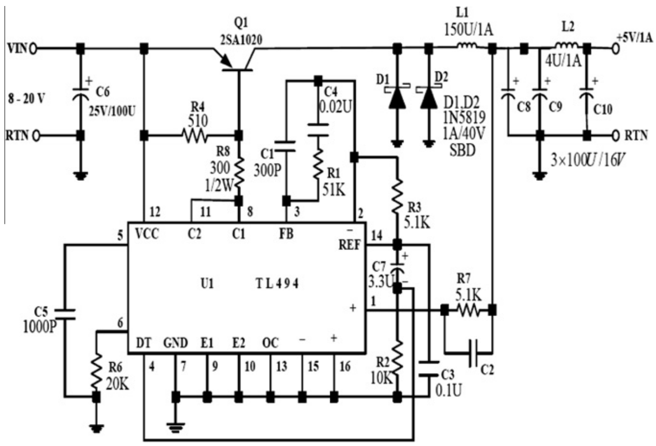

Fig. 2. Boost converter circuit.

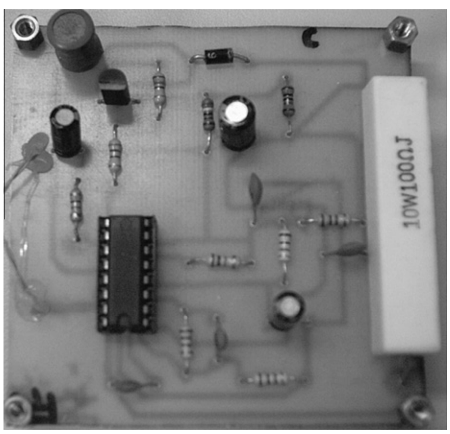

Fig. 3. Real boost converter circuit.

an inductor to resist changes in current. When being charged it acts as a load and absorbs energy (somewhat like a resistor), when being discharged, it acts as an energy source (somewhat like a battery). The voltage it produces during the discharge phase is related to the rate of change in current, and not the original charging voltage, thus allowing different input and output voltages.

3.2. Designs the matter-element model of thermal images

The circuit under test already operates for a period of time. Thermal-image analyzing instruments are then used to observe each electronic element temperature variation. If the temperature has obvious variations, a photograph is taken, as shown in Fig. 4. Users can observe the temperature spread through Fig. 4. All temperature degree pictures were taken through the thermometer under the picture. Moreover, the designer can decide the circuits that need several judgment areas as the characteristics.

We decided to select three judgment areas as the characteristics to build matter-element and c_1, c_2, c_3 shows the three characteristics in Fig. 4. Moreover the characteristics of value v are to find out the upper limit and lower limit of temperature. Therefore, the matter-element model can be described as follows:

$$R = \begin{Bmatrix} N & c_1 & v_1 \\ & c_2 & v_2 \\ & c_3 & v_3 \end{Bmatrix} \tag{8}$$

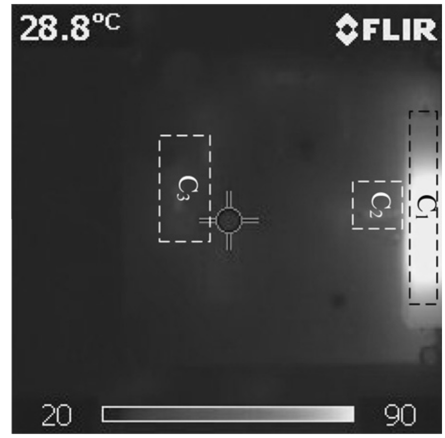

Fig. 4. The thermal image of boost converts circuit.

4. The extension fault diagnosis method

This paper simulated several fault conditions and observed the thermal images of the electric circuits, for fault condition used in building matter-element model. This diagnosis system can be used in diagnosing circuits under testing.

4.1. The fault diagnosis methods of extension

We completed computer software for circuit faults and the algorithm can be described as follows:

Step 1: Establish the matter-element model of every circuit fault category. Suppose there are three thermal images, included Fig. 5 No fault, Fig. 6 resistance open, Fig. 7 capacitance open and Fig. 8 inductance open.

The above four thermal images would find the different temperatures for dispersion situation. Each classic domain of characteristic values choose a range that is selected at the maximum and minimum temperature to set a classic domain $\langle a, b\rangle$, and the circuit fault matter-element model is shown in Table 2.

Step 2: To charge with untested circuit broad and taking thermal images to build matter-element models

$$R_t = \begin{Bmatrix} N_t & c_1 & v_{t1} \\ & c_2 & v_{t2} \\ & c_3 & v_{t3} \end{Bmatrix} \tag{9}$$

Step 3: Calculating the correlation function of the circuit under test with the characteristic of each e fault matter-element by the proposed extended correlation function as follows:

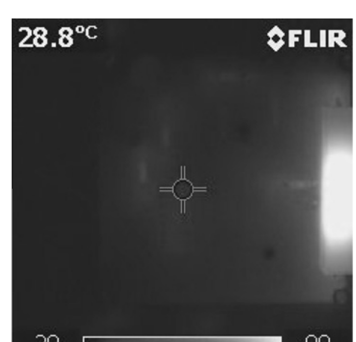

Fig. 5. No fault.

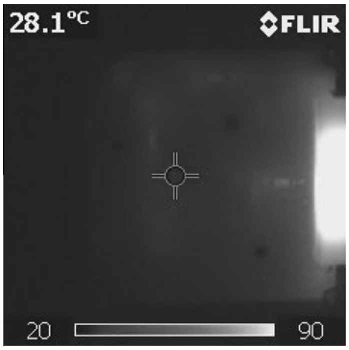

Fig. 6. Resistances open.

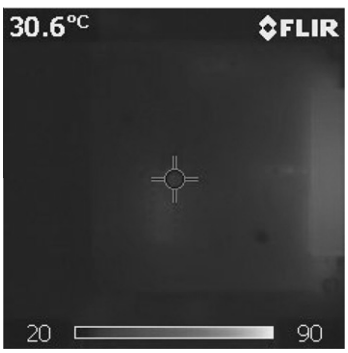

Fig. 7. Capacitances open.

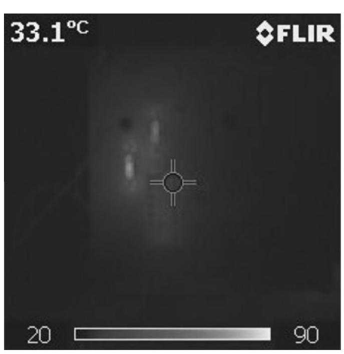

Fig. 8. Inductance open.

Table 2
The matter-element model of circuit fault.

Fault type	Matter-element model
No fault	$R_1 = \begin{Bmatrix} N_1 & c_1 & v_{11} \\ & c_2 & v_{12} \\ & c_3 & v_{13} \end{Bmatrix}$
Resistances fault	$R_2 = \begin{Bmatrix} N_2 & c_1 & v_{21} \\ & c_2 & v_{22} \\ & c_3 & v_{23} \end{Bmatrix}$
Capacitances fault	$R_3 = \begin{Bmatrix} N_3 & c_1 & v_{31} \\ & c_2 & v_{32} \\ & c_3 & v_{33} \end{Bmatrix}$
Inductance fault	$R_4 = \begin{Bmatrix} N_4 & c_1 & v_{41} \\ & c_2 & v_{42} \\ & c_3 & v_{43} \end{Bmatrix}$

$$K_{ij}(V_{ti}) = \begin{cases} \frac{\rho(V_{ti},V_{ij})}{-1} & V_{ti} \in V_{ij} \\ \frac{\rho(V_{ti},V_{ij})}{\rho(V_{ti},V_{pi})-\rho(V_{ti},V_{ij})} & V_{ti} \notin V_{ij} \end{cases} \tag{10}$$

Here

$$\begin{aligned} \rho(V_{ti}, V_{ij}) &= \left| V_{ti} - \frac{a_{ij}+b_{ij}}{2} \right| - \frac{b_{ij}-a_{ij}}{2} \\ \rho(V_{ti}, V_{ij}) &= \left| V_{ti} - \frac{a_{pi}+b_{pi}}{2} \right| - \frac{b_{pi}-a_{pi}}{2} \\ i &= 1,2,3,4; \quad j = 1,2,3 \end{aligned} \tag{11}$$

Step 4: Assigning weights to the circuit fault characteristic such as W_{i1}, W_{i2}, W_{i3}, are denoting the significance of every circuit fault characteristic. In this paper, W_{i1}, W_{i2}, W_{i3}, are set as $W_{i1} = W_{i2} = W_{i3} = 1/3$.

Step 5: Calculate the correlation degrees for every category:

$$\lambda_i = \sum_{j=1}^{3} W_{ij} K_{ij} \quad , i = 1,2,\ldots,4 \tag{12}$$

Step 6: Make each correlation function for every engine fault in $\langle 1, -2 \rangle$, that is easy to diagnosis.

$$\lambda'_i = \frac{3\lambda - \lambda_{\min} - 2\lambda_{\max}}{\lambda_{\max} - \lambda_{\min}}, \quad i = 1,2,\ldots,4 \tag{13}$$

which

$$\lambda_{\max} = \max_{1 \leqslant i \leqslant 4}\{\lambda_i\}, \quad \lambda_{\min} = \min_{1 \leqslant i \leqslant 4}\{\lambda_i\} \tag{14}$$

Step 7: Confirming what kind of the engine fault is it? If λ_f then the engine fault is the main type. The possibility of other faults is

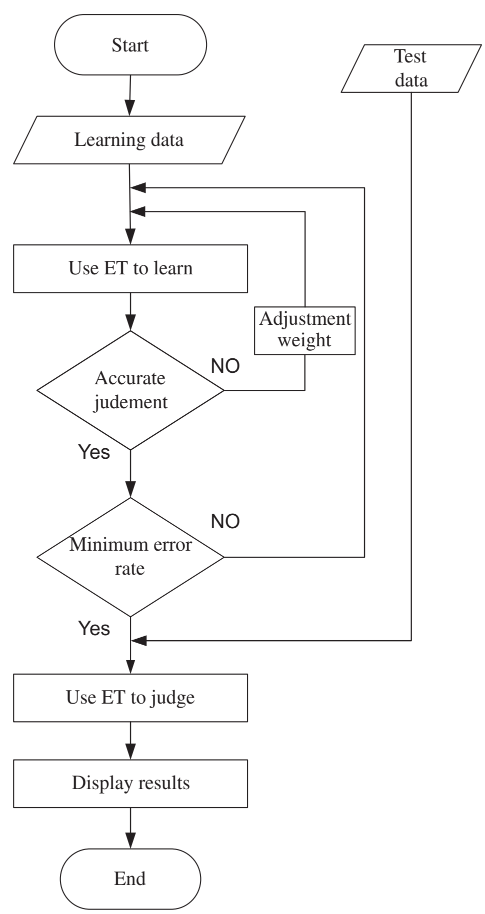

Fig. 9. Processing chart of this research.

based on the correlation function. If the correlation function is larger, the engine fault is larger.

Step 8: If all kinds of the engine faults have been diagnosed, then end, or go back to step 2 to next case.

This research presents fault diagnosis method basically on extension theory. It has the advantage of less judgment time and need not remain in touch with the circuit, so it can reduce the opportunity for damage. This fault diagnosis method will save time and manpower than the traditional ones.

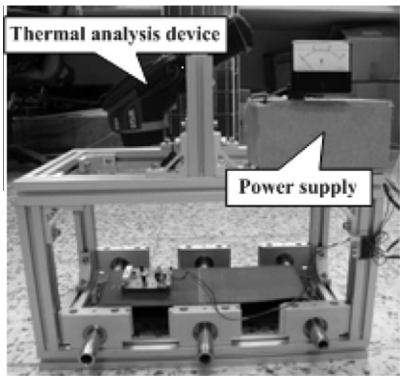

Fig. 10. Imitate device.

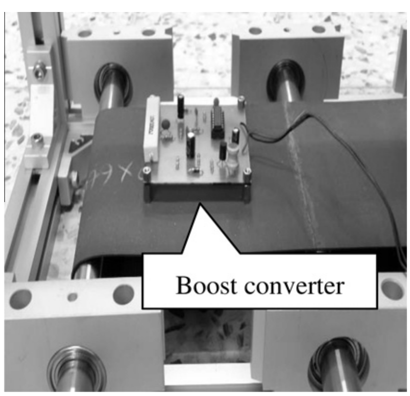

Fig. 11. Production line model.

4.2. Experiment step square picture

This paper put forward fault diagnosis method. Fig. 9 shows the experiment steps in square pictures.

5. Research results and discussion

This research method tells that we can use the computer software to estimate its function after using heat-analysis machine to photograph thermal images for building the matter-element models of faults, it will cause an error of estimation because the situation of every thermal-image was different if photographed by hand. Therefore, appliances are needed to hold the heat-analysis machine for photographing to ensure that the situation is the same in every thermal-image.

5.1. Rudiment system of photographed thermal images

This research designed a rudimentary system that imitated industry conditions, shown in Figs. 10 and 11. This system included a fixed thermal analysis device, production line, power supply. This method can increase the stability of taking thermal images and develop a kind of production equipment.

We chose a boost converter circuit because it is quick and simple to manufacture.

5.2. The software of thermal diagnosis

The thermal diagnosis software makes a matter-element model of the thermal images, The circuit board processes thermal images to estimate if the circuit is normal or not and what types of faults are present. The software interface is shown in Fig. 12.

This software can build every kind of matter-element thermal image model. This experiment built four matter-element models from thermal images: including normal operation, resistance fault, capacitance fault, and inductance fault. We can input wanted

Fig. 12. Thermal diagnosis software interface.

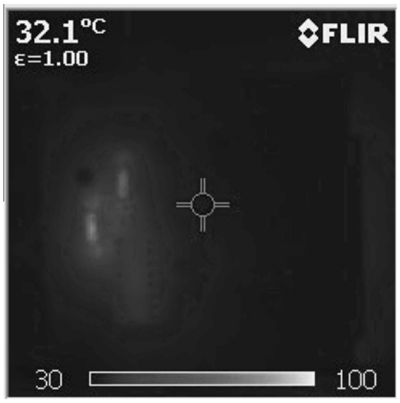

Fig. 13. Test circuit boards of thermal images.

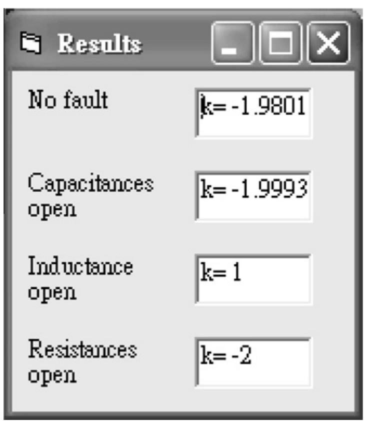

Fig. 14. Display result of correlation degreed.

estimated thermal images and start to calculate the correlation of every matter-element model after the matter-element set.

5.3. Actual testing result

First a thermal image is photographed of the testing circuit as in Fig. 13, the testing circuit board can be detected fast according to correlation degree between the typical fault models and testing circuit boards as in Fig. 14, the correlation between an inductance fault and testing circuit is the biggest one. The computer can estimate that the circuit has an open inductance fault.

To take into account errors and uncertainties, this paper utilizes 200 measured data to verify each fault type using 50 measured data, with 10 data used as the training module. The diagnosis method was able to identify a fault with excellent accuracy. Table 3 demonstrates the capability of the diagnosis system in isolating single faults in the test circuit.

Table 3
Diagnosis performances of accuracy rate.

Fault type	Accuracy rate (%)
No fault	96
Resistances open	94
Capacitances open	100
Inductance open	100

6. Conclusion

This paper presented a no contact fault diagnosis method for circuit boards. The experimental results show that the proposed thermal images fault diagnosis method can easily determine faults in test circuit boards. The features of the proposed fault diagnosis method include reaching fast judgment and reducing time. The proposed method can also operate automatically. Fault diagnosis on larger, more complex circuits is more complex and difficult because we have to set the eigen-value and matter-element parameters. However, we can increase the recognition if we take all breakdown matter-element settings to match the matter-element vector design. This can save more time to gain efficiency and reach breakdown recognition faster. In the future, using this fault diagnosis method we can reduce defections in electronic devices.

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