Design and Implementation of ESD Immunity Test for a Combustible Gas Alarm Device

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Abstract. In this paper, a series of electromagnetic compatibility tests were carried out on a combustible gas alarm device. In order to ensure the Electrostatic Discharge (ESD) performance of the device, some targeted solutions for electrostatic protection were proposed. Finally, the device passed the test based on analysis and rectification and met the evaluation index in GB/T 1726.3-2018 well, which is very significant to improve the quality and reliability for this kind of products.

1. Introduction

In industrial field, the combustible gas alarm device is a commonly used alarm instrument for gas concentration detection. According to the current national standard GB/T 1726, a series of electromagnetic compatibility tests were carried out on the device. It was found that the device was very sensitive to ESD, which often caused the restoration and fault alarm in the circuit board. After analyzing and rectifying based on these phenomena, some targeted solutions were summarized and proposed.

Figure 1. The Structure of the Device

The PCB main board of the device adopts four layers board design, including the top layer, the GND layer, the power layer and the bottom layer in order, the key board adopts two layers design, including the top layer and the bottom layer. The lower computer controlled by MCU can monitor the power status...
signal in order to process, transmit. In addition, it can also communicate with upper computer in real
time so as to alarm various fault detected by the lower computer and the upper computer. The structure
of the device is shown in Fig.1.

2. Esd Immunity Test

2.1. Test Standards
ESD immunity test has two kinds of ways including direct discharge and indirect discharge [1]. In this
paper, the performance of the alarm was tested by direct discharge, which was closer to the actual
situation. According to the current national standard GB/T 1726.3-2018 [2], the test equipment includes
electrostatic discharge generator and electrostatic gun discharge electrode. General test grades are shown
in Table 1.

| Level | Contact discharge Test Voltage (kV) | Air discharge Test Voltage (kV) |
|-------|-----------------------------------|-------------------------------|
| 1     | 2                                 | 2                             |
| 2     | 4                                 | 4                             |
| 3     | 6                                 | 8                             |
| 4     | 8                                 | 15                            |
| X     | Special                           | Special                       |

2.2. Test Methods
- Confirming that the test device is in normal working condition. Then arranging the device, cable
  and other test instruments.
- Selecting the test voltage grade and discharge point positions of the device.
- Discharging 10 times of positive charge and 10 times of negative charge on the pre-selected points
  respectively with the rate of 1 time per second, so as to make the alarm respond [3].

The initial test adopted test grade 3 with contact 6kV discharge voltage and 8kV air discharge voltage.
The selections of the discharge point on device are shown in Fig.2.

![Figure 2. The Discharge Point Selected on the Device](image)

As shown in Fig.2, point ① is the position of the keyhole, point ② are positions of LED indicator
lights, point ③ are positions of screen edges and corners, point ④ are positions of buttons, point ⑤ are
positions of a number of holes in the device shell. The initial test results are shown in Table 2.
Table 2. Initial Test Result

| Voltage | Discharge Mode | Test Situation | Phenomenon                        |
|---------|----------------|----------------|-----------------------------------|
| 6kV     | Contact        | unqualified    | Circuit board generated fault alarm. |
|         |                |                | ⑤ Circuit board reset.            |
| 8kV     | air            | unqualified    | Circuit board reset.             |

3. Analysis of the Initial Test Result
From the initial test results, the device was obviously affected by the electromagnetic field generated by ESD and the sensitive discharge point position was the keyhole. Under the condition of 6kV contact discharge, the circuit board generated fault alarm and turned on all of the amber lights while there is no fault in the device when discharging at point ⑤ on both sides of the device shell. At the same time, under the condition of 8kV air discharge, the circuit board reset when discharging at point ①. The test was not passed, so rectification should be carried out. When each discharge point of the device was tested, several different working states of the circuit board are shown in Fig.3 and Fig.4.

According to the theory of electrostatic discharge, ESD can interfere with the device in two ways. One is conducted interference, that is, some part of the circuit constitutes a discharge path, which causes ESD enters into the device directly and then interferences with the circuit board. The other is radiation interference, that is, the peak current generated by ESD generates radiation electric field and radiation magnetic field. The magnitude of radiation interference depends on the distance between the circuit and the electrostatic discharge point. The magnetic field generated by ESD decays with the square of the distance, while the electric field generated decays with the cubic of the distance. Since the circuit board was very close to the electrostatic discharge point because of the design of the device, ESD may generate a very strong near-electromagnetic field causing interference to the circuit board.

Considering the relevant technical requirements of electrostatic emission immunity test and the above analysis of the test results, the problem can be located in the following possible reasons:
- The shielding performance of the device shell is not perfect, leading to ESD entered into the circuit board of the device directly and caused interference.
- There are some defects in the design of PCB.
4. Analysis of Rectification Scheme

4.1. Treatment of the Keyhole

- The anti-static lock can be replaced, which can effectively prevent ESD from being directly discharged onto the device circuit board.
- A cable which connects the position of the lock with the device shell can be added in the device. The specific rectification scheme is shown in Fig.5 and Fig.6.

![Figure 5. Rectifying Physical Circuit](image)

![Figure 6. Hybrid Ground Connection Strategy](image)

As shown in Fig.6, $R_1$, $R_2$ and $R_3$ are ground impedances of $AD$, $AB$ and $CD$ in node $A$, $B$, $C$ and $D$. And $I_1$, $I_2$ and $I_3$ are respectively the current of ESD discharge loop, peripheral circuit of the device and PCB circuit. In the ground connection design of the device, the ESD discharge circuit and the peripheral circuit of the device first adopts the method that the common ground wire connects with ground by one-point in series, and then adopts the method that the one-point of independent ground wire connect with ground in PCB circuit. That point is point $D$ which corresponds to the device shell.

According to KCL law, there is:

$$I_4 = I_1 + I_2$$  \hspace{1cm} (1)

According to KVL law, there is:

The potential of point $D$:

$$U_D = I_1R_1 = (I_1 + I_2)R_1$$  \hspace{1cm} (2)

At the same time:

The potential of point $B$:

$$U_B = (I_1 + I_2)R_1 + I_2R_2$$  \hspace{1cm} (4)
As shown in Fig.6, a cable added in the device that connected the lock position with the device shell. The method proposed can provide a discharge channel for the ESD discharge current, which corresponds to the AD section. The PCB circuit can be separated from ESD discharge circuit and the peripheral circuit of the device by connecting the one-point of independent ground wire with ground. In this way, the ground potential of the circuit board can be only related to the ground current of the PCB circuit and the impedance of the ground wire [4]. On the other hand, ESD will discharge to the ground quickly, which can protect the circuit board from being interfered effectively.

4.2. Electrostatic Protection Treatment of the Circuit Board

The bi-directional TVS transient suppression diode can be added to the power module, and the specific rectification circuit is shown in Fig.7.

![Figure 7. Rectification Circuit Of Power Supply Module](image)

The reason why the circuit board adopted bi-directional TVS diode instead of unidirectional TVS diode is that the pre-selected discharge point of the device needs to be discharged positive charges and negative charges respectively and the circuit board may withstand voltage shock from both directions. On the other hand, bi-directional TVS diode can absorb large instantaneous pulse power in both positive and negative directions and it can also set the voltage to a predetermined level, which can effectively suppress the overload pulse brought by ESD and protect the power supply [5].

4.3. Rectification Test

After the above rectification of the device, the rectification test was conducted again under the same test conditions as the initial test. In order to illustrate the effectiveness of the rectification scheme, the test grade was increased as follows: The contact discharge voltage and air discharge voltage were increased by 10% from fixed 6kV and 8kV to fixed 6.6kv and 8kV respectively. The test results of the modified device are shown in Table 3.

| Voltage | Discharge Mode | Test situation | Phenomenon |
|---------|----------------|----------------|------------|
| 6kV     | contact        | qualified      | /          |
| 6.6kV   | contact        | qualified      | /          |
| 8kV     | air            | qualified      | /          |
| 8.8kV   | air            | qualified      | /          |

Through the rectification test results, it was found that no matter in the same test condition or in the increased test level condition, the problem has been completely solved, and there was no such phenomenon as the circuit board reset or generated fault alarm has happened again. The device passed the ESD immunity test eventually and met the performance evaluation index well.

5. Conclusion

In this paper, some targeted solutions were summarized and proposed based on the analysis and rectification for ensuring the ESD performance of the device to meet the evaluation index in GB/T
1726.3-2018. According to the initial test results and the test results of different coping measures on the device, there are two major reasons why the device is difficult to pass the test: First of all, the shielding performance of the device shell is not perfect, so that the ESD interference signal almost needn’t to be coupled, but can easily entered into the device from the shell, which can interfere with the circuit board. Secondly, the interference suppression of electrostatic is not well designed, such as lacking of some targeted EMI suppression components in the Circuit Board before rectification. According to the final test results, the solutions proposed and adopted in this paper have achieved some good results, ensuring the ESD immunity performance of the device.

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