A New cooling system based on Piezoelectric fan

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Abstract. For a control box with concentrated power consumption, high heat generation, and small volume requirements, the paper designed a new piezoelectric fan cooling system. The system used piezoelectric ceramics as the fan blade drive module, could achieve directional, efficient and reliable heat dissipation, ensured stable and safe operation of key components. The composition and characteristics of the new piezoelectric fan module were introduced in detail. The simulation results were compared by Flotherm software based piezoelectric fan module in off and on states.

1. Introduction
With the rapid development of electronic technology, the size of electronic equipment was getting smaller and smaller, and the power consumption density of the equipment was getting larger and larger, which brought severe challenges to the reliability of electronic equipment. The current common fault causes distribution diagram of electronic equipment was shown in Figure 1. 55% of the failure rate of electronic components was caused by the temperature exceeding the maximum allowable operating temperature of the electronic components. Therefore, the heat problem had been identified as one of the three major problems (strength and vibration, heat dissipation, and electromagnetic compatibility) in the design of electronic equipment[1].

Figure 1. Distribution of electronic equipment failure causes

As a system control unit, the control box was the core of the entire system. It mainly included 10 circuit modules such as MCPU board, VGB board, COM board, CPU board, etc. The power consumption of the whole machine could reach 75W. In recent years, the modules inside the control box had gradually shifted towards miniaturization and integration. In the case of limited design space and increasing integration, the overheating problem inside the control box was prominent. During the
previous project development, there had been problems such as the control box crashing due to chip overheating under high temperature conditions, which caused the equipment to fail to operate normally.

At present, the control box mainly realized heat dissipation through a combination of natural cooling and air cooling. In high temperature environments, axial fans were generally used to achieve air cooling and heat dissipation. However, traditional axial fan cooling had many limitations, including: (1) Electromagnetic interference; (2) Poor dust-proof effect; (3) Unable to meet high temperature and high humidity salt spray environment; (4) Requirements for installation space.

In this paper, a new type of air cooling system was designed for a certain type of control box. This system used piezoelectric ceramics as the drive module of the fan blades, which could realize fast, effective, stable and reliable heat dissipation of the control box. The structure of the new cooling system of the control box was introduced in detail. The actual effects of the piezoelectric module on and off were modeled and compared by special Flotherm thermal stress modeling simulation software[2].

2. Piezoelectric Fan System Composition
The piezoelectric fan system used the inverse piezoelectric effect of piezoelectric ceramics to convert electrical energy into vibration. Piezoelectric ceramics itself vibrated under a certain voltage. When the vibration frequency reached the natural frequency, its vibration amplitude was the largest. Then the piezoelectric ceramic vibration was transmitted, amplified, through metal or other materials. The free end of a metal (or other material) amplifier swung back and forth under the action of an electric field to achieve the purpose of accelerating the air flow. This method strengthened the use of natural heat dissipation or replaced the breeze air cooling fan, and realized heat dissipation of the heating device[3].

In the early design of a control box, a combination of natural cooling and axial fan was used to dissipate heat (see Figure 2). However, it was found in the test that the axial fan had poor performance in terms of dust resistance and salt spray resistance, and couldn’t meet the long-term and highly reliable operation in harsh use environments. In addition, the axial fan had a large volume, which had certain requirements for the installation space. Therefore, in the new round of design improvement of the control box, a piezoelectric fan module was selected as the heat dissipation system. The piezoelectric fan accelerated the air flow and improved the radiation heat dissipation ability of the control box.

The structure of the control box was shown in Figure 3. The control box mainly included an upper cover component, a box component, and a panel component. On the basis of maintaining the original structure, the piezoelectric fan module was arranged in the upper cover assembly to replace the original axial fan assembly. After the piezoelectric fan module was used, the overall height of the control box was reduced by 12mm. The detailed structure of the piezoelectric fan cover assembly was shown in Figure 4, and the main components were shown in Table 1.

The cover assembly mainly included: (1) An aluminum alloy cover substrate with heat dissipation fins. The cover substrate was designed with fin-type heat dissipation fins on the opposite side of the piezoelectric fan, which greatly increased the heat dissipation area and improved the radiation heat dissipation effect. In addition, air inlet holes and air outlet holes were designed on the front and rear end faces of the piezoelectric fan to reduce the flow resistance. (2) Piezoelectric fan modules, consisting of two groups, each consisting of 7 piezoelectric ceramic modules, were fixed on the opposite side of the fins, could provide airflow with good orientation and high wind speed. (3) Drive power module: provided stable power for piezoelectric fan modules. (4) The perforated cover, the array openings on the top and the air inlet and outlet of the upper cover substrate formed a heat flow channel to reduce the flow resistance.
Figure 2. Axial fan cooling structure

Figure 3. Heat dissipation structure of piezoelectric fan in control box

Figure 4. Piezoelectric fan module structure

Table 1. Composition of the cover assembly

| Serial number | Name                  | Note                                      |
|---------------|-----------------------|-------------------------------------------|
| 1             | Cover substrate       | With fins and air inlets and outlets      |
| 2             | Piezoelectric fan module | Two groups                              |
| 3             | Drive power           | Power conversion                          |
| 4             | Perforated cover      | Air inlet and outlet                      |
| 5             | Power connector       | Provides 26V for the drive power module   |
The biggest advantage of the piezoelectric fan was that because of its high vibration frequency, the concentrated wind did not spread, the directivity was good, the speed was fast, and there was no magnetic leakage, which overcame the shortcomings of traditional fans, such as poor directivity, slow wind speed and easy diffusion. At the same power, its air cooling effect was obviously better than traditional fans. In addition, other performance indicators of the piezoelectric fan were also significantly better than traditional fans. It had simple structure, small size, light weight, low noise, long life, automatic lock-up when power was off, etc. The specific performance indicators were as follows:
- Input voltage range: DC12V ~ DC28V
- Output voltage range: DC80V ~ 180V
- Working frequency: 50Hz ~ 100Hz
- Power consumption: single set of piezoelectric fan power consumption ≤ 3W
- Output wind speed: V = 3m/s, up to 6m/s
- Noise: less than 45Db
- Temperature control: start working above 20 degrees Celsius
- Leakage protection: with leakage protection function

3. Comparison of Cooling Effect of Piezoelectric Fan
After the design of the three-dimensional model was completed, the thermal stress distribution of the control box under the high temperature of 65°C was simulated by the Flotherm simulation software. The thermal stress distribution of the piezoelectric fan module under two states of on and off was simulated respectively. By comparing the temperature distribution inside the control box under these two different working conditions, the feasibility of the heat dissipation performance of the piezoelectric fan module was verified, and a comparison data description was given.

3.1. Simulation Data Information Collection
The control box consisted of 10 modular components and was installed in a closed metal box. The specific module components and their power consumption were shown in Table 2. In order to meet the requirements of light weight, strength and rigidity of electronic equipment at the same time, the casing of the box was made of ZL104 aluminum alloy, which was processed by the whole aluminum block milling. In order to improve the radiation and heat dissipation, the external surface of the whole machine was treated with jade white electrostatic spraying, and the surface emission coefficient ε (blackness) was greater than 0.8. The inner surface of the case was golden conductive oxidation. Each module's heatsink was milled from 6063 aluminum alloy.

The initial environmental conditions of the control box were shown in Table 3.
Table 2. Control box module composition

| Serial number | Module name   | Quantity | Power consumption /W | Operating mode    | Machine power consumption /W |
|---------------|---------------|----------|-----------------------|-------------------|------------------------------|
| 1             | MCPU board    | 1        | 13.3                  | Long-term work    | 75                           |
| 2             | VGB board     | 1        | 11.97                 | Long-term work    |                              |
| 3             | COM board     | 1        | 9.31                  | Long-term work    |                              |
| 4             | CPU board     | 1        | 4                     | Long-term work    |                              |
| 5             | A/D/A board   | 1        | 4                     | Long-term work    |                              |
| 6             | IO board      | 1        | 2.66                  | Long-term work    |                              |
| 7             | KZB board     | 1        | 2.66                  | Long-term work    |                              |
| 8             | DY1 board     | 1        | 26.6                  | Long-term work    |                              |
| 9             | DY2 board     | 1        | 16                    | Long-term work    |                              |
| 10            | BASE board    | 1        | 0                     | Long-term work    |                              |

Table 3. Initial environmental conditions

| Environmental conditions | Environmental control conditions |
|--------------------------|---------------------------------|
| Ambient temperature      | 65°C                            |
| Ambient air pressure     | 1.01×10⁵Pa                      |
| Ambient air velocity     | 0                               |
| Fluid name               | Air                             |
| Inlet temperature        | 65°C                            |
| Flow / Flow rate         | 0                               |

3.2. **Piezoelectric Fan was off**

When the piezoelectric fan was not energized, the temperature distribution inside the control box was modeled and simulated. After calculating and solving by Flotherm software, the overall temperature field distribution of the control box under the platform ambient temperature of 65°C was shown in Figure 5. The maximum temperature inside the control box was 82.79°C. The highest temperature appeared on the DY1 board.

![Figure 5. Cloud diagram of temperature distribution (fan was off)](image-url)
3.3. **Piezoelectric Fan was on**

When the piezoelectric fan was energized, the temperature distribution inside the control box was modeled and simulated. The outlet wind speed of the piezoelectric fan module was $V=3\text{m/s}$.

After calculating and solving by Flotherm software, the temperature field distribution of the control box under the platform ambient temperature of $65^\circ\text{C}$ was shown in Figure 6. The maximum internal temperature of the control box was $67.6^\circ\text{C}$. The highest temperature appears on the DY1 board.

![Figure 6. Cloud diagram of temperature distribution (fan was on)](image)

The simulation results showed that the temperature of the top fan cooling module was low and uniform. The temperature difference between the top cooling module and the ambient temperature was also very small ($<1.0^\circ\text{C}$), indicating that the heat dissipation capacity was sufficient. In addition, the suction effect of the piezoelectric fan also helped to enhance the chimney effect of the side wall airflow, thereby enhancing the heat dissipation of the side wall, as shown in Figure 7.

![Figure 7. Flow field distribution of the piezoelectric fan](image)

3.4. **Comparison of Product Simulation Results**

Table 4 showed the temperature simulation results of the control box when the piezoelectric fan module was turned off and on. The comparison of the results showed that the temperature of the device could be reduced by $12^\circ\text{C} \sim 13^\circ\text{C}$ compared with the natural heat dissipation by using a piezoelectric fan module, and the piezoelectric fan module had a large heat dissipation potential that had not been tapped. In addition, in order to make full use of the heat dissipation capacity of the piezoelectric fan module, the heat dissipation path of the board to the fan heat dissipation module on the top of the box should be optimized, and the thermal resistance on this path should be reduced to increase the introduction of heat. From the perspective of cost, the number of piezoelectric fans could
be reduced (only a wind speed of about 3m/s could be provided to lower the temperature by 12°C ~ 13°C).

| Cooling form                  | Maximum temperature (Tmax) | Lowest temperature (Tmin) |
|-------------------------------|-----------------------------|----------------------------|
| Natural cooling (Turn off the piezoelectric fan) | Cabinet temperature 71.3°C | Cabinet temperature 70.3°C |
|                               | Board temperature 82.8°C   | Board temperature 70.6°C   |
| Forced cooling (Turn on the piezoelectric fan) | Cabinet temperature 63.8°C | Cabinet temperature 61.9°C |
|                               | Board temperature 67.6°C   | Board temperature 62.8°C   |

4. Conclusion
The traditional fan cooling system had been difficult to meet the requirements of the development of electronic technology, and the problems caused by electromagnetic interference and low reliability needed to be solved. The piezoelectric fan cooling system was essentially a supplement to the air-cooled system. It had the advantages of directional fast heat dissipation, no electromagnetic interference, high temperature resistance, low power consumption, long life, and low noise. In order to meet the requirements of stable operation in harsh environments, a new type of piezoelectric fan cooling system was designed for a certain type of control box, replacing the original axial fan cooling structure. Simulation analysis of the temperature of the control box in the closed and open state of the piezoelectric fan module proved that the piezoelectric fan module could effectively dissipate heat to the control box. In addition, the piezoelectric fan had a compact structure, which could directly act on high-density heat sources, and could also be applied to other complex and changeable structures to achieve directional heat dissipation in a small space.

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