Thermal Design of Control Panel Systems

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Abstract. With the miniaturization, integration, and modularization of aerospace avionics, the installation density of electronic components has significantly increased. Consequently, thermal design for electrical devices and heat dissipation problem in printed circuit boards (PCBs) has emerged as critical challenges. Grounded in heat transfer theory, this paper systematically summarizes conventional heat dissipation method. Taking the control power supply unit of a civil aircraft as a case study, the study quantitatively compares operational temperature differentials before and after thermal optimization. The results validate the effectiveness of the proposed heat dissipation method, demonstrating measurable enhancements to aviation safety.

Keywords: Thermal Design; Power Module; Control Panel System.

1. Introduction

As aerospace avionics continue to trend toward compact size and high-performance capabilities, components within these systems are rapidly evolving toward high-density integration architectures [1]. Taking the cockpit control panel system of a civil aircraft as an example, the control panel assembly provides essential electrical components required for aircraft systems status monitoring and flight operation control. As a device with high internal integration, the increased packaging density of the control panel assembly inevitably leads to a continuous increase in power density within the components, which results in increased heat generation and cooling difficulties for the device. The structural rationality of the control panel assembly's heat dissipation system exerts critical influence on the operational longevity and functional reliability [2, 3]. In accordance with the Arrhenius equation, the failure rate of electronic components approximately doubles with every 10°C increase in operational temperature [4]. And, approximately 55% of electronic component failures are attributable to operational temperature beyond specified design limits [5]. Therefore, adequate consideration should be given to heat dissipation issues in the design of control panel assembly to prevent local overheating that can lead to chip burnout and functional failure. This study analyzes common heat dissipation methods and applies in the thermal design of control panel assembly system to enhance the reliability.

2. Heat Transfer Theory

To achieve rational and effective thermal design for control panel assembly, it is imperative to adhere to heat transfer theory. The three fundamental modes of heat transfer are conduction, convection, and radiation.

2.1 Heat Conduction Theory

Thermal conduction primarily refers to the process of heat transfer between two objects in contact with a temperature difference, or between different temperature regions within the same object, occurring in the absence of macroscopic material displacement [6, 7]. Thermal conductivity varies significantly due to the combined effects of microscopic particle vibrations (e.g., molecules, atoms, and electrons) and differences in heat transfer mechanisms within materials.

2.2 Heat Convection Theory

Convection primarily refers to the heat transfer phenomenon between a solid surface and a flowing fluid during the process of fluid passage over the solid surface [6, 7]. In natural, convective heat transfer is a widely prevalent phenomenon observable across numerous objects.

2.3 Heat Radiation Theory

Radiation refers to the process by which objects transfer energy through electromagnetic waves. In the context of heat dissipation, the process where an object emits energy in the form of electromagnetic waves is termed thermal radiation [6, 7]. In the process of energy transfer, objects at higher temperatures tend to transfer energy to those at lower temperatures.

3. Common Heat Dissipation Design

Based on the aforementioned heat transfer theories, several common thermal design methods for component heat dissipation are outlined below.

3.1 Heat Dissipation Device Design

First, we can add heat sinks to the components. When selecting materials for heat sinks, factors such as thermal conductivity, cost, and manufacturability must be thoroughly considered. In terms of metallic materials, silver offers superior thermal conductivity, but its high cost makes it less economically viable. Therefore, considering both thermal performance and cost-effectiveness, aluminum alloy emerges as the optimal choice for primary heat dissipation material [6].

The design of the heat sink's dimensions is equally critical. Heat sinks primarily dissipate thermal energy through radiation and convection, with their cooling performance optimized by increasing the total effective surface area for heat exchange [8]. Therefore, increasing the length of the heat sink can reduce the junction temperature of the device. However, if the heat sink is too long, it not only fails to ensure effective heat transfer to the end of the heat sink but also increases the weight of the heat sink [9]. For the longitudinal dimension of the heat sink, increasing its thickness has minimal impact on reducing the junction temperature and can also lead to an increase in the weight of the heat sink. However, to ensure the stiffness of the heat sink and ease of manufacturing, the thickness should not be too thin; generally, it should be ≥1mm.

Additionally, the number of heat sinks should also be considered. The design principles for the number of heat sinks are similar to those for thickness: increasing the number has minimal impact on the junction temperature and can make installation more difficult. Therefore, it is not advisable to blindly increase the number of heat sinks.

In addition to adding heat sinks, another approach is to design internal cavities within the device to increase air circulation inside, thereby enhancing heat dissipation

3.2 PCB Heat Dissipation Design

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3.2.1 Power Chip Optimization

First, select power supply chips with low heat generation rates and reduce the turn-on current to minimize chip power consumption and surface temperature. Secondly, if the heat sources in the power chip are overly concentrated, mutual thermal coupling between major heat sources can occur, making it difficult for internal heat to dissipate effectively [10]. Therefore, during the design of power chips, attention must be paid to maintaining adequate spacing between adjacent modules.

3.2.2 Thermal Via

Thermal vias are small holes drilled through PCBs, typically with diameters ranging from 0.4mm to 1.0mm. The aperture should not be excessively large, and the via spacing is recommended to be set between 1.0mm and 1.2mm. Drilling holes in the PCB can alter the overall flow field inside the device. Since the air inside the device is in a state of natural convection, drilling holes allows some of the cooler air from the lower layers to flow directly to the high-temperature areas, thus cooling them and reducing the chip temperature [11]

3.2.3 PCB Copper Pour

Copper Pour (PCB Copper Pour) enhances circuit anti-interference capability and promotes effective heat dissipation in PCBs [12]. Common copper pour methods include solid copper pour and hatched copper pour. Solid copper pours on PCBs carry the risk of strip-like copper foil detachment after overheating during operation; therefore, hatched copper pour is more commonly adopted.

4. Application and Summary

In a certain aircraft control panel assembly system, the control power supply frequently malfunctions due to overheating during operation, leading to failures in some lighting functions, which seriously hinders pilots' ability to interpret and respond to the core system status and fault information of the aircraft, compromising flight safety. Based on the common heat dissipation design methods for control panel assembly systems, the faulty control power supply has been optimized by adding heat sink, increasing internal cavities in the device, replacing the power chip with one that has a lower heat generation rate, and optimizing the layout of the power module. The test results show that the temperature of the optimized power module has decreased by approximately 80% compared to before the optimization, significantly improving the efficiency of the equipment.

Based on heat transfer theory and actual cooling requirements, this paper summarizes common cooling methods, including the addition of heat dissipation devices and PCB heat dissipation design. In the thermal design of control panel assembly components and their electronic parts, the operational temperature of the power module has been significantly reduced through the installation of heat sinks and optimization of power supply chips, thereby enhancing equipment reliability and aircraft operational safety.

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