World Journal of Innovation and Modern Technology, Vol. 7, Issue 5, (Oct)
ISSN 2682-5910 2024

DOI: 10.53469/wjimt.2024.07(05).11

Enhancing the Heat Dissipation Efficiency of Computing Units Within Autonomous Driving Systems and Electric Vehicles

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Abstract: ***With the rapid development of autonomous driving technology and electric vehicles, the demand for computing units in vehicles has surged, particularly for high-density computing related to artificial intelligence, sensor fusion, and real-time data processing. This increase has posed significant heat dissipation challenges for automotive electronic systems. Effective heat dissipation is essential for ensuring system stability, safety, and extending the lifespan of these systems. This study explores the thermal design of computing units in current autonomous driving systems and electric vehicles. The electronic components within the computing units generate significant heat, but due to environmental constraints, fans can not be used for internal cooling, as their operation can draw in dust from the environment, contaminating the internal electronic components. Therefore, computing units are often designed with a sealed structure, utilizing the thermal conductivity of metal casings to quickly dissipate internal heat sources. The results of this study show that comparing embedded cooling modules within the casing to commonly used thermal pads reveals that changing the materials of the cooling module can significantly enhance cooling performance, noticeably reducing the temperature of the internal electronic components and minimizing the risk of overheating. Additionally, this can improve the overall reliability and performance of the system, providing new ideas and application prospects for future automotive thermal design.***

Keywords: Autonomous driving systems; Electric vehicles; Computing units; Heat dissipation.

1. INTRODUCTION

In recent years, the development of autonomous driving technology and electric vehicles (EVs) has highlighted the critical role of the performance and stability of computing units. As the demand for autonomous driving systems increases, the sensors, radars, cameras, and other equipment within vehicles generate a vast amount of data, which raises higher requirements for real-time processing and computational capabilities. However, high-performance computing units generate a significant amount of heat when operating for extended periods in the confined environment of a vehicle. Insufficient heat dissipation can lead to decreased computational efficiency and may even affect system stability and safety.

The promotion of electric vehicles has accelerated the application of automotive computing units, and these systems, under the trend of miniaturization and high performance, are more susceptible to overheating challenges. Traditional cooling solutions, such as fans or liquid cooling technologies, can address heat dissipation issues to some extent, but they are often costly, complex in structure, and may negatively impact the driving range and operational reliability of electric vehicles. Therefore, enhancing the heat dissipation performance of computing units in autonomous driving systems and electric vehicles while considering economic viability and sustainability has become a focal point of interest in both academia and industry.

This study aims to explore the application of innovative cooling technologies to optimize the working environment of computing units in autonomous driving and electric vehicles, thereby improving their stability and computational performance, and providing a more reliable technological foundation for the future development of intelligent transportation systems.

2. COMMON HEAT TRANSFER FACTORS IN DESIGN

2.1 Selection of Casing Materials

In order to ensure that the machine can operate in harsh working environments, special attention is given to material selection for heat dissipation issues. Poor heat dissipation can easily lead to reduced machine performance and, in severe cases, can cause system crashes, thereby affecting safety.

Although aluminum's thermal conductivity is only surpassed by gold, silver, and copper, at 237 W/(m•k), aluminum alloys have advantages such as low density, high strength, and excellent electrical and thermal conductivity. Their good overall performance is widely applied in industries such as aerospace, automotive, machinery manufacturing, electronics, and communications [1,2,3,4]. Considering the above advantages along with weight and cost, aluminum alloy materials are typically the preferred choice.

2.2 Casing Appearance Design

The thermal conduction in materials occurs due to an internal temperature imbalance, causing heat to transfer from high-temperature areas to low-temperature areas through contact points. The temperature passing through a unit cross-sectional area in a unit time under a unit temperature gradient is known as thermal conductivity. The expression for thermal conduction is as follows:

$$\Delta Q = -\lambda \frac{dT}{dx} \Delta S \Delta T \tag{1}$$

where, ΔS is the cross-sectional area, ΔQ is the energy passing through the section, Δt is the time, dT/dx represents the temperature change in the x direction, and λ is the thermal conductivity [w/(m•k)]. The negative sign indicates that the direction of heat transfer is opposite to the direction of the temperature gradient.

To address this, the internal structure of the chassis is specially designed to be close to high-power heating electronic components, allowing the heat generated by these components to be quickly conducted outward. When thermal energy is transferred from the heating components to the material of the case, to avoid the problem of heat accumulation after reaching thermal equilibrium, it is desirable to dissipate the heat to the external environment as quickly as possible. Therefore, the exterior of the case cannot be designed as a smooth flat surface. According to the formula mentioned above, to enhance energy transfer, the cross-sectional area can be increased to accelerate the transfer. Thus, the exterior of the chassis can be equipped with fin structures to increase the contact area with the external air, thereby accelerating heat dissipation, as illustrated in Figure 1.

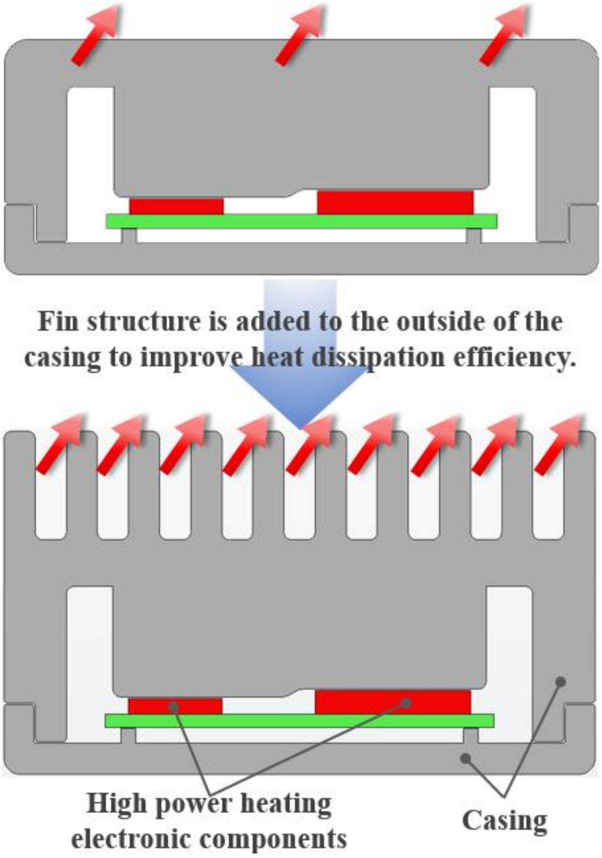

Figure 1: Diagram of the case illustrating how to increase cooling efficiency.

2.3 Selection of TIM

For high-power heating electronic components with a high unit density of heat on their surfaces, the continuously generated thermal energy is conducted to the thermal conductive components through thermal conduction, ultimately achieving thermal equilibrium without overloading the thermal conductive components of the product (e.g., casing, heat sink, etc.). Since there will be contact surfaces between different components, when heat is conducted, there will be an interface thermal resistance that needs to be considered. Additionally, the surfaces of the materials will have microscopic irregularities that are not visible to the naked eye, which significantly reduces the contact area between the two. At this point, it is necessary to use Thermal Interface Material (TIM) to fill the tiny gaps and surface irregularities that occur when the two materials are joined or in contact, in order to reduce the thermal transfer resistance; otherwise, it will severely hinder thermal conduction, as illustrated in Figure 2.

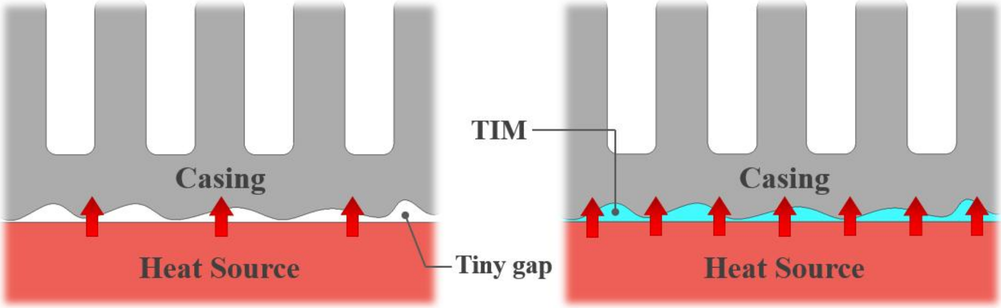

Figure 2: Diagram of TIM usage location.

The types of thermal interface materials include thermal silicone sheets, thermal adhesive tapes, thermal pastes, thermal adhesive compounds, etc. This study selects thermal pads, which are also known by various names such as thermal silicone mats, thermal silicone sheets, flexible thermal mats, etc. Generally, they are composed of silicone combined with thermal conductive powders, flame retardants, and other materials to achieve different properties such as thermal conductivity, insulation, and compressibility. They also have self-adhesive properties, making assembly extremely convenient, as they can be operated without any tools, similar to stickers.

3. DESIGN OPTIMIZATION FOR HEAT DISSIPATION EFFICIENCY

There are many models and types of aluminum alloy materials, each with different advantages (e.g., corrosion resistance, impact resistance, thermal conductivity, machinability, etc.). The design of fins to increase the heat dissipation surface area on the exterior of the chassis focuses on the relationship between the thickness of the fins [5], the spacing between the fins, and the thickness of the fin base. If the thickness of the fin base is larger, the corresponding fins must be thinner; conversely, if the base thickness is smaller, the fins must be thicker. The thickness of the fins, combined with the spacing between them, indicates that thicker fins require larger spacing, while thinner fins require smaller spacing. For optimizing heat dissipation design [6,7], there are two important factors: how to achieve the goal with lower cost and space. Generally, there are two methods: first, using the relationship between the shape and cross-sectional area of the fins, and the overall volume of the fins in the heat dissipation base along with the total number of fins to determine the optimal depth of the fins; second, using the number and volume of the fins to find the optimized depth and geometric shape of the fins.

Regarding the selection of thermal pads, their main purpose is to fill the gaps between two materials. The closer the distance between the two materials, the more effectively heat is transferred, which can also reduce thermal resistance and improve thermal conductivity. Therefore, the thinner the pad, the better the thermal efficiency. Additionally, a higher thermal conductivity coefficient (the ability of a material to conduct/transfer heat) is generally preferred. Currently, common thermal pads on the market have a thermal conductivity coefficient of 5 W/(m•k). We conducted experiments comparing this with another pad that has a higher thermal conductivity coefficient of 10 W/(m•k) by adding more thermal conductive powder. We found that the surface temperature of electronic components decreased by about 2 ~ 3 °C. However, it is important to note that choosing a higher thermal conductivity coefficient also significantly increases the price, so a comprehensive evaluation of whether the cost is reasonable and worthwhile is necessary.

Due to concerns that the operation of fans can easily bring dust from the environment into the system, potentially contaminating internal electronic components, the computing units of autonomous driving systems and electric vehicles are often designed to be fanless and sealed. These computing units typically require high-density computations, and if heat is not dissipated in a timely manner, it can lead to overheating of electronic components, reduced computational performance, and even the risk of system crashes. Therefore, more efficient heat dissipation methods need to be considered. As mentioned earlier, gold, silver, and copper all have good thermal conductivity. From a cost perspective, selecting copper and aluminum (for the casing material) and comparing their thermal conductivity coefficients and specific heat capacities reveals that "copper conducts heat faster than aluminum, but aluminum dissipates heat faster than copper." Thus, it is considered to replace the parts close to the heat-generating electronic components with copper material, allowing heat to be conducted away from the electronic components more quickly, and then the aluminum chassis can rapidly transfer the heat to the external environment. The design concept involves disassembling the structure of the original aluminum alloy casing specifically for the heat dissipation part, as illustrated in Figure 3. After thermal simulation, it was found that the maximum temperature of the electronic components could decrease by about 8 ~ 10 °C.

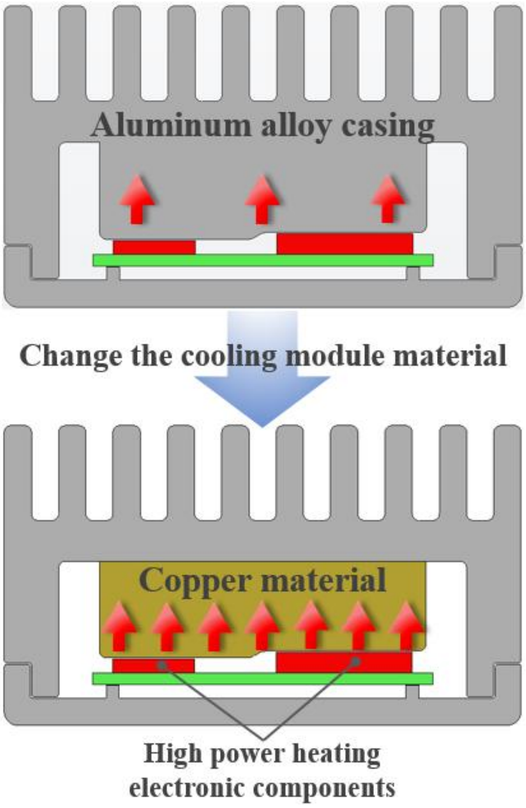

Figure 3: Diagram of changing the cooling module.

4. CONCLUSION AND OUTLOOK

For fanless systems with high-density heat-generating electronic components, the design direction to enhance heat dissipation efficiency is to consider how to quickly conduct heat away from the electronic components. Therefore, this study directly addresses the conduction path of the heat source. While the choice of thermal pads can slightly lower temperatures, it is still not as efficient as disassembling the heat dissipation module into copper materials. Additionally, this disassembly has the advantage of allowing the aluminum alloy casing to be modularized, enabling the addition of copper heat dissipation modules at the corresponding electronic components that require cooling for various electronic boards.

In response to different installation conditions, it may even be considered to attach a waterproof and dustproof fan to the external fins of the chassis to accelerate the heat dissipation efficiency of the fins, allowing the internal electronic components' heat to be conducted out more quickly. Furthermore, it may also be considered to design the finned casing as a liquid cold plates structure, embedding the cooling pipes within it, which can further enhance the thermal conductivity efficiency of the heat dissipation module. These are all directions for my future in-depth research and exploration.

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