International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 10 Issue: 07 | July 2023 www.irjet.net p-ISSN: 2395-0072

Designing a Heat sink for motor controller unit

Aryan Raval[1], Vishal Dagra[2], Jaydip Prajapati[3], Parth Prajapati[4], Prof. Kalpesh Vaghela[5]

[1-5]*Automobile dept, L.D. college of engineering,*
Opp Gujarat university, Navrangpura, Ahmedabad, Gujarat, India, 380015

Abstract - This *research paper presents a detailed investigation into the design and optimization of a heat sink specifically tailored for the motor control unit (MCU) in an electric vehicle which controls the motor of power rating of 1500 Watts, while taking into account constraints such as mass, temperature, and dimensions. The primary objective is to develop a heat sink design that efficiently dissipates the heat generated by the MCU, while simultaneously satisfying the thermal requirements and minimizing size and weight. A systematic and analytical approach is employed, including computational simulations and numerical analysis techniques to model and predict the thermal behavior of the heat sink. By iterating through different configurations, optimal dimensions are identified, balancing heat dissipation efficiency and the overall mass of the heat sink.*

***Key Words*: Heat sink, MOSFETs, MCU, Electric Vehicles, Heat dissipation**

1.INTRODUCTION

The increasing demand for electric vehicles (EVs) has spurred remarkable advancements in the field of electric powertrain technology. Within an electric vehicle, the motor control unit (MCU) plays a crucial role in managing the power flow and ensuring efficient motor performance. However, the operation of the MCU generates substantial heat, which, if not properly dissipated, can lead to performance degradation, reliability issues, and even component failure. Therefore, effective thermal management of the MCU is of paramount importance to ensure its optimal functioning and longevity.

The investigation focuses on the design and optimization of a heat sink specifically tailored for the MCU in an electric vehicle. The aim is to develop a heat sink design that efficiently dissipates the heat generated by the MCU while simultaneously satisfying critical constraints such as mass, temperature, and dimensions. The ultimate goal is to minimize the size and weight of the heat sink while maintaining its thermal performance within acceptable limits.

To achieve this objective, a systematic and analytical approach is adopted, combining computational simulations and numerical analysis techniques to model and predict the thermal behaviour of the heat sink. By employing these methods, various heat sink configurations and dimensions are explored, enabling the identification of optimal designs that strike a balance between heat dissipation efficiency and the overall mass of the heat sink. In this research, a case study is conducted to evaluate and compare the thermal performance of two different heat sink designs under various parameters. The case study provides insights into the effectiveness of different design choices in enhancing heat dissipation for the MCU in electric vehicles. By analyzing the performance of these designs under different operating conditions, this study aims to identify the most efficient heat sink design that optimally dissipates heat generated by the MCU while considering factors such as geometry, surface area, and overall dimensions.

The design process begins with a thorough understanding of the thermal characteristics of the MCU, considering factors such as the power dissipation of the MCU and the ambient operating conditions. An accurate thermal model is established, serving as the foundation for conducting computational simulations to evaluate different heat sink designs under varying thermal loads. For the current study peak loads are considered which could be achieved at maximum output of 2500 W which produces 70A of peak current through the MCU circuit.

Through iterative simulations and analyses, the performance of each heat sink design is assessed in terms of its ability to dissipate heat effectively and maintain acceptable temperatures within the MCU. The simulations provide insights into the thermal behaviour of the heat sink, helping to identify areas of improvement and optimization.

Furthermore, the numerical analysis techniques employed in this research aid in predicting the thermal performance of the heat sink under real-world operating conditions. Factors such as natural convection, forced convection, and radiation heat transfer are considered, leading to a more accurate representation of the heat sink's behavior and enhanced design decisions.

The findings of this research contribute to the development of an optimized heat sink design that effectively dissipates the heat generated by the MCU in an electric vehicle having set to the current configuration of power outputs. The proposed design not only ensures the thermal reliability and longevity of the MCU but also aims to minimize the size and weight of the heat sink, addressing the weight and space constraints typically associated with electric vehicles.

The rest of this paper is organized as follows. Section 1 provides an overview of the significance of thermal management in electric vehicles, highlighting the importance of efficient heat dissipation in the MCU. Section 2 discusses the methodology employed in this research, outlining the computational simulations and numerical analysis techniques utilized. Section 3 presents the results and analysis, showcasing the optimized heat sink designs and their corresponding thermal performance and discusses the implications and practical applications of the research findings, highlighting the potential benefits for electric vehicle manufacturers. While concluding the paper by summarizing the key contributions.

By addressing the critical issue of heat dissipation in the motor control unit of electric vehicles, this research aims to enhance the thermal management strategies in electric powertrain systems, contributing to the overall design, efficiency, and reliability of MCUs in electric vehicles in the emerging era of sustainable transportation.

1.1 Topography of MCU:

A motor controller unit, or MCU, is an electronic device designed to regulate the operation of an electric motor. It plays a vital role in receiving input signals, processing them, and generating output signals to control various aspects of the motor's performance, including speed, direction, and other relevant parameters. To understand the technical workings of an MCU, we delve into its core functionalities:

The MCU is powered by a suitable power source, such as a battery or power supply unit, which provides the necessary voltage and current levels for both the MCU's internal circuitry and the connected motor. The motor taken into account has a rated power output of the motor is 1500 W which produces peak current of 70 amperes and peak power output of 2500 W. The maximum voltage drop rating for this specification of motor is 48 Volts.

Control inputs, sourced from switches, sensors, or microcontrollers, are received by the MCU. These inputs encompass commands relating to motor speed, direction, and other operating parameters.

To ensure motor and MCU safety, protection features may be included. These features encompass overcurrent protection, overtemperature protection, short-circuit protection, and fault detection mechanisms.

By combining these components and functionalities, the MCU effectively regulates the operation of an electric motor, offering precise control over its speed, direction, torque, and other parameters according to the specific requirements of the application at hand.

Because of various factors involved, there is fundamental risk of overheating the MCU. Overheating in an MCU can have significant consequences on its performance and reliability. Two primary effects of overheating in an MCU are reduced efficiency and degraded component lifespan.

When an MCU operates at high temperatures, its internal resistance increases, leading to higher electrical losses and which also leads to lower power output for the motor. This decrease in efficiency affects the overall energy conversion and utilization within the MCU. As a result, the motor control system may experience reduced efficiency, increased power consumption, and potential degradation in system response and accuracy. Overheating can also accelerate the aging and deterioration of electronic components within the MCU, such as capacitors, resistors, and integrated circuits. This degradation shortens the lifespan of these components, leading to more frequent failures and the need for replacement or repairs.

Moreover, overheating can trigger a phenomenon known as thermal runaway. In extreme cases, the heat generated by the MCU surpasses its ability to dissipate heat effectively, resulting in a rapid increase in temperature. Thermal runaway can lead to system failures, compromised motor control, and potential damage to the MCU and connected components if not promptly addressed.

To mitigate these effects, proper thermal management techniques should be employed. This includes ensuring sufficient airflow around the MCU, utilizing heat sinks or cooling systems, and regularly monitoring temperatures. By maintaining optimal operating conditions and preventing excessive heat buildup, the MCU's efficiency can be preserved, and the longevity of its components can be extended, ensuring reliable motor control operations.

1.2 Importance of MOSFETs:

MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) have a pivotal role in motor controller units (MCUs), contributing to efficient and precise control of electric motors. They primarily function as power switches, regulating the current flow to the motor. Within the context of a research paper, we can explore the specific roles performed by MOSFETs in MCUs:

One fundamental function of MOSFETs is power switching. These semiconductor devices serve as electronic switches, enabling or interrupting the connection between the power supply and the motor. MOSFETs, known for their high current and voltage handling capabilities, provide reliable control over the motor's operation. When turned on, MOSFETs deliver power to the motor, while turning them off blocks the current flow.

MOSFETs play a vital role in Pulse-Width Modulation (PWM), a commonly used technique in motor control. Within the motor drive circuitry of the MCU, MOSFETs facilitate the conversion of PWM signals into high-power signals that effectively drive the motor. By rapidly switching the MOSFETs based on the PWM duty cycle, precise control over the motor's speed is achieved by regulating the average voltage applied to the motor.

Efficiency and heat dissipation are key considerations in motor control. MOSFETs contribute significantly to these aspects. With their low on-resistance (Rds(on)), MOSFETs exhibit minimal resistance when fully activated, resulting in reduced power losses and improved system efficiency. In the current circuit there are total of 24 different MOSFETs which are connected in series in sets of 4. Their fast switching characteristics minimize switching losses. Effective thermal management techniques ensure proper heat dissipation, maintaining optimal operating conditions.

MOSFETs also provide crucial protection and safety features. They incorporate overcurrent protection, swiftly interrupting the current flow when it exceeds predefined thresholds, thus safeguarding the motor from potential damage. Additionally, MOSFETs offer short-circuit protection, preventing excessive current flow during fault conditions, ensuring the safety of the MCU.

Furthermore, MOSFETs enable dynamic braking and motor reversal capabilities, enhancing control over motor operations. By strategically activating and deactivating the MOSFETs, the motor's current flow can be rapidly interrupted or reversed. This capability enables smooth and controlled braking or reversal of the motor's rotation, expanding the versatility and functionality of the motor control system.

In conclusion, MOSFETs serve critical functions in motor control applications within MCUs. Acting as power switches, they enable efficient PWM control, provide protection mechanisms, facilitate dynamic braking and motor reversal, and enhance overall system performance. By harnessing the capabilities of MOSFETs, precise and effective control of electric motors can be achieved.

2. Comparing two distinct designs:

The two designs in question have gone through rigorous drawing board designing and both being completely distinct from each other, pursues different design philosophies. Design “A” follows a much more conservative design language while on the contrast design “B” has bolder approach. Fundamental characteristics of both the designs are discussed in sections 2.2 and 2.3. Both the designs follow a design constrains which are inherited by them from the system, all the constraints and design methodology is discussed in section 2.1 further along.

2.1 Design approach:

Heat sink design involves considering all the given constraints ad optimizing the design after going through various iterations of hand calculations and computational simulations. Though it is bit tough to determine the exact step to step guide for the designing process as each case tend to vary a lot, basic design tree looks something similar to this:

1. Determination of heat sink requirements: Start by understanding the specifications and thermal characteristics of the component you want to cool. Identify its maximum heat dissipation, operating temperature, and any thermal limitations provided by the manufacturer.

2. calculation of thermal requirements: Calculate the required thermal resistance (Rth) for your heat sink. Rth is the temperature difference between the component and the ambient air, divided by the power dissipated, in this case peak power and current passing through the component. The lower the Rth, the more efficient the heat sink will be.

3. Analyze the dimensional constraints: Assess the available space and physical constraints where the heat sink will be installed. Consider the dimensions, shape, and any mounting requirements. Ensure that the heat sink can fit within the given space.

4. Selection of heat sink material: Choose an appropriate material for your heat sink. Aluminum and copper are commonly used due to their high thermal conductivity. Copper has better heat conductivity but is more expensive than aluminum. Consider other factors like weight, cost, and compatibility with your application.

5. Determination of heat sink size: Determine the size of the heat sink based on the amount of heat it needs to dissipate. This involves calculating the surface area required to achieve the desired heat transfer. The heat sink's surface area is directly proportional to its cooling capacity.

6. Choosing the heat sink configuration: Decide on the heat sink configuration based on your requirements and available space. Common configurations include finned heat sinks, pin heat sinks, and heat pipes. Fins increase the surface area for better heat dissipation.

7. Design the heat sink structure: Design the heat sink structure considering the selected configuration. Decide on the number, shape, and arrangement of the fins or pins. Ensure uniform spacing for efficient airflow. The design should promote laminar airflow and minimize pressure drops.

8. Perform thermal simulations and calculations: Use thermal simulation software or manual calculations to assess the heat sink's thermal performance. Analyze parameters such as thermal resistance, pressure drop, and temperature distribution. Modify the design as needed to optimize the performance.

9. Incorporate other cooling methods: Consider other cooling methods to complement the heat sink, such as fans or liquid cooling systems. Determine if these additional methods are necessary based on the heat load and ambient conditions.

10. Prototype and test: Once you have finalized the design, create a prototype of the heat sink. Conduct testing to evaluate its effectiveness in real-world conditions. Measure temperature differentials and assess thermal performance. Iterate on the design if required.

Design A:

Design A has been developed with holding the conservative design language. The design had dimensional constraints of (250*160*10 mm) given that the heat sink needs to be mounted on the top of the MCU. The Target temperature T is 60° C. The current passing through the MOSFETs is 70 A with junction resistance of 0.0031 ohm. The voltage drop in MOSFETs is about 0.217 Volts. The fin gaps are optimized in Design A to 4 mm and fin thickness is 6 mm with fin length being 5 mm. The temperature reached after heat dissipation with ambient temperature being 40 degrees Celsius. The MOSFETs are fixed to an aluminum block with thermal paste which acts as a mounting point for the MCU inside the aluminum encloser. Aluminum is chosen here because of its thermal conductive properties and its relatively inexpensive nature as compared to other materials like copper. The encloser is designed with ease of access as a priority and primary goal, therefore it has a removable sliding panel in one of the sides.

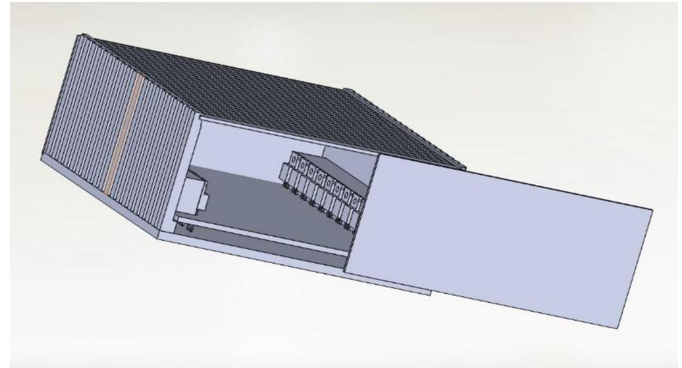

Fig -1: Design A

The simulation analysis shows that the design reaches the target temperature with the current fin dimensions quite comfortably with the mounting of the MOSFETs on the aluminum block.

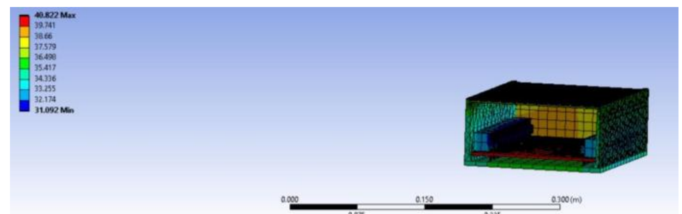

Fig -2: Analysis of Design A

Design B:

Design B falls under similar constraints which are, (250*16*10 mm). The target temperature for this design is 50°C as there are changes in fin dimensions as well as change in the mounting point. The junction resistance is 3.1 mili ohms. The ambient temperature around the thermal enclosure is 40° Celsius. The MOSFETs are fixed to the heat sink with the help of thermal paste and the PCB is bolted to the enclosure. The external fins have 5 mm gap with 10mm length. And the internal fins have 7 mm length with 4 mm gap between them.

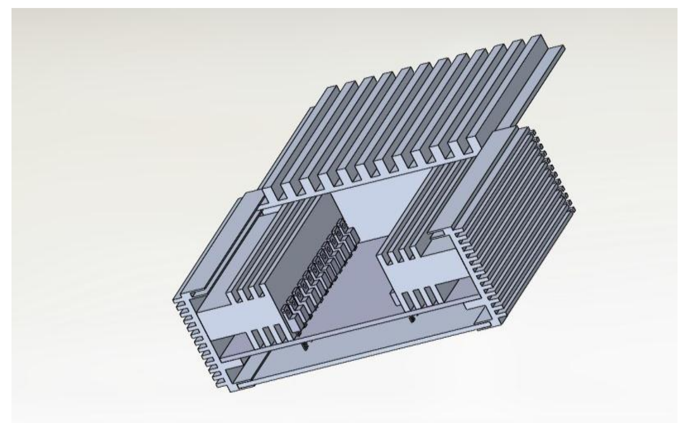

Fig -3: Design B

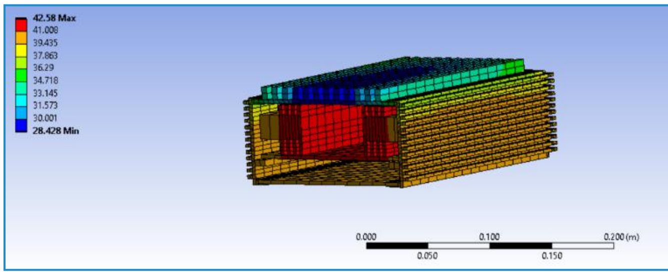

Fig -4: Analysis of Design B

Table -1: Comparison of designs.

Fields	Design A	Design B
Target temperature	70° C	60° C
Constraints	250*16*10 mm	250*16*10 mm
Fin dimensions	4*6*5 mm	5*5*10 mm
Max temperature	40.822	42.58

3. CALCULATIONS

3.1 Heat flow rate:

Heat flow rate,

$$Q = (K*A*n*\Delta T)*X1 / X2$$

Where,

K = thermal conductivity constant

A = Area of fins

n = number of fins

ΔT = change in temperature

Fin with w = 200 mm

Fin thickness = 5 mm

$\Delta T = 40$

Plugging in the values we get heat

Q = 63.084 Watts.

3. CONCLUSIONS

In conclusion, the above manuscript provides a comprehensive investigation into the design and optimization of a heat sink tailored specifically for the motor control unit (MCU) in electric vehicles operating under peak load. The study aims to develop an efficient heat sink design that effectively dissipates the heat generated by the MCU, while satisfying the thermal requirements and minimizing size and weight constraints.

To achieve this objective, a systematic and analytical approach was employed, which showed that both designs are compatible to the MCU under peak current conditions (70 A) both in terms of heat dissipation and dimensional constraints.

This findings contribute to the advancement of thermal management in electric vehicles, addressing the critical challenges associated with designing the heat sink and explaining the step-by-step process of designing a heat sink.

The computational simulations and numerical analysis techniques employed in this research provide a robust framework for evaluating the thermal behavior of the heat sink. Moreover, the iterative nature of the study allows for the exploration of a wide range of configurations, facilitating the identification of the most effective heat sink design. This iterative process involves evaluating various geometries, materials, and structural features, ensuring that the final design meets the thermal requirements while minimizing the size and weight of the heat sink. By leveraging computational simulations, the performance of each design iteration could be assessed, reducing the need for costly and time-consuming physical prototypes.

References:

1) K Tripathi and M Shreejeth, “Thermal Study of MOSFET heat sinks for Motor Controller in Neighborhood Electric Vehicles (NEV),” International Journal of Electric and Hybrid Vehicles · April 2022.

2) S. Ravikumar and P. Chandra, “Experimental and Transient Thermal Analysis of Heat Sink Fin for CPU processor for better performance,” IOP Conference Series: Materials Science and Engineering, Volume 197, Frontiers in Automobile and Mechanical Engineering7–9 July 2016.

3) A. kumar and K. Londhe, “Heat sink design for optimal performance of compact electronic appliances-a review,” Research gate, October 2017.

4) S. Deshmukh and Chandrashekhar Nagendra, "Review on Heat Sink Design and Material," International Journal of Trend in Scientific Research and Development (ijtsrd), Volume-5, Issue-3, April 2021.

5) Krishnamoorthy and T. Jayakumar, “Design and Development of Aluminum-based Heat Sink for Electronic Gadgets,” International Journal of Recent Technology and Engineering (IJRTE), Volume-7, Issue-5S3, February 2019.

6) P.S. Patel and D.G. Shubhedar, “Cooling performance analysis of heat sink,” IJAR, Volume 1, Issue 9, June 2012.

7) K. Sinha and P. Ahirwar, "Computational Analysis of Heat sink or Extended Surface," IRJET, Volume 4, Issue 6, June 2017.

BIOGRAPHIES

Aryan Raval
Aspiring automobile engineer, currently pursuing bachelor's in automobile engineering from L.D.CE.

Vishal Dagra
Student in L.D.C.E pursuing bachelor's degree in automobile engineering.

Jaydeep Prajapati
Student in L.D.C.E pursuing bachelor's degree in automobile engineering

Parth Prajapati
Student in L.D.C.E pursuing bachelor's degree in automobile engineering

Kalpesh Vaghela
Assistant professor, Automobile department, L.D college of engineering.