Design and development of cooling system of battery in an electric two wheeler

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Abstract - *This project is based on designing a casing with fins of battery for cooling of a two-wheeler electric vehicle battery using forced convection. In the recent years, electric vehicles have a boom in the industry due to its zero emission of gases and also electric vehicles is four times as energy efficient than of IC engine. Electric vehicles (EVs) are becoming more and more popular as the automotive industry develops around the world. Due to their benefits, including their outstanding energy density, good power density, and low self-discharge, lithium-ion (Li-ion) is commonly used in electric vehicles (EVs). To enable an increased lifespan, cheaper costs, and for better safety, the batteries must be operated within their optimal range for safety and excellent thermal management. The primary goal is to develop a fin design that can speed up heat transfer in an electric vehicle battery. A proper management is needed in order to achieve the maximum performance when operating at different conditions. A proper cooling is always necessary for a battery in order to control the battery thermal behavior. The aim is to analyze the temperature rise in Lithium-ion batteries due to charging and discharging in electric vehicles and to provide an engineering solution for the same.*

Key Words: Thermal Runaway, management, module, simulated, fins, lithium-ion.

1. INTRODUCTION

1.1 Electric Vehicles:

For many years the internal combustion engine has dominated the transportation sector, now the electric vehicles are on the verge of having rapid growth in vehicle markets. The widespread adoption of electric vehicles might have a huge impact on society, not just in terms of the technology we use for personal mobility, but also in terms of shifting our economies away from petroleum and reducing transportation's environmental imprint. The mechanics of an electric automobile are often significantly simpler than those of a conventionally driven vehicle.

The following are a few instances given by EV:

1). An electric motor has fewer moving parts than a gasoline engine.

2). An electric car is fitted with a single-speed transmission. Electric cars, unlike traditional autos, are not equipped with many of the common parts that break down and need to be replaced or repaired.

1.2 Lithium-Ion Batteries:

Because of its high energy per unit mass compared to other electrical energy storage methods, lithium-ion batteries are presently employed in most portable consumer gadgets 1 such as mobile phones and laptops. They also feature a high power to weight ratio, excellent high-temperature performance, and minimal self-discharge. Lithium-ion (Li-ion) batteries have risen in prominence in recent decades as a viable power source for a variety of applications, including electric and hybrid cars, power grids, and solar energy storage. Li-ion batteries are widely recommended as a power source in extended driving ranges and quick acceleration because of its high power density, dependability, and longevity. Li-ion batteries, on the other hand, create heat during quick charge and discharge cycles at high current levels. Furthermore, temperature and inhomogeneity have a significant impact on their energy storage capability and durability.

1.3 Battery:

The high temperature of Li-ion battery cells has been shown in several studies to accelerate capacity deterioration and limit battery life. Heat buildup in batteries causes safety concerns and abnormalities across the electric vehicle system. Overheating, scorching, and battery explosion are just a few of the dangers. Thus, the design and development of an effective thermal management system (TMS) remains a crucial challenge in the electric vehicles industry. For Li-ion batteries, the ideal working temperature range is 25–40 °C. The Li-ion battery's temperature range achieves a balance between performance and longevity. Fast charging/discharging modifications have put an urgent challenge on battery power performance and the battery TMS in order to achieve faster speed, acceleration, and shorter charging time of the battery pack Degradation is strongly temperature-dependent, with a minimal degradation around 2 25 °C, i.e., increasing if stored or used at above or below 25 °C. High charge levels and elevated temperatures (whether from charging or ambient air) hasten capacity loss. To fulfill the heat dissipation requirement of Li-ion batteries, different cooling solutions in the form of active, passive, and hybrid are investigated. TMS are used to manage the heat generated by electrical devices and batteries during operation, such as phase change materials (PCM) and nanomaterials, heat pipes, air, and liquid cooling systems.

1.4 Thermal runaway:

Thermal runaway in lithium-ion (Li-ion) batteries occurs when a cell, or a portion of a cell, reaches dangerously high temperatures as a result of thermal breakdown, mechanical failure, internal/external short circuiting, or electrochemical abuse. Exothermic breakdown of the cell components begins at high temperatures. When the cell's self-heating rate exceeds the rate at which heat can be dispersed to the surroundings, the temperature of the cell rises exponentially, and stability is lost. As a result of the loss of stability, all remaining thermal and electrochemical energy is discharged into the environment.

1.5 Causes of thermal runaway:

As the name suggests, internal short circuit is basically a short circuit which takes place inside of the cell. We also know that short circuit releases huge amount of energy and this energy is generated in the form of heat. Internal short circuit in Li⍰ion batteries is a process by which anode and cathode meet each other internally. So, when anode and cathode come into contact then huge amount of heat is generated and this leads to thermal runaway in a cell. There are many reasons how internal short circuit takes place in a cell of a battery. Internal short circuit takes place because of some accident or mechanical failure leading to deformation of a battery material. This battery material deformation may lead to breakage of separator wall thus allowing both anode and cathode to meet each other. So, when the internal short circuit happens by collision or crush that is by mechanical abuse then there are chances of leakage of flammable electrolyte from the cell again this isa very serious issue and can cause thermal runaway.

2. MATERIAL SELECTION

Once the basic design is complete, it is necessary to perform its analysis to determine its viability for the specified parameters and to choose the appropriate material with an eye towards optimizing the vehicle's performance. We have chosen three materials from the research in the literature study that are typically used to make battery fins because they are lightweight and good heat dissipation. Al 2024 T6, steel, and copper are the materials that have been selected.

Material	Al 2024 T6	Steel	Copper
Thermal conductivity	120	30-50	401
Thermal Diffusivity	84-100	10-20	117
Strength to weight ratio	240-270	30-200	120-240

Table 1: Material Comparison

The material for casing is selected as Aluminium alloy 2024 T6, the reason behind selecting the material is high thermal diffusivity, high thermal conductivity, high strength to weight ratio and the main reason is because of light weight. The fins are also considered as the same material as that of casing which is Aluminiun alloy 2024-T6.

3. CALCULATION

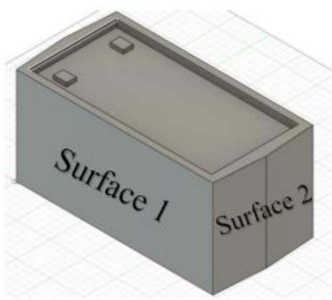

Fig.1: Distinguished Battery surfaces

Heat generation in a battery:

The battery is discharge at a 2C rate
The current (I) for 2C rate is 30A
Total heat generation in Battery (Energy)
Power=60×30 = 1800 W
Energy loss as heat

$\dot{Q}_1$=nxI^2xR= 32× $(30)^2$× (10×10^{-3}) =288 W

% of heat loss = 288/1800 = 16%

Energy loss as a heat= 288 W

$\dot{Q}\ \alpha$ A

A1 = 27.2 × 12.5 = 340 cm^2

$A2 = 13 \times 12.5 = 162.5\ cm^2$

$\dot{Q}_1/\dot{Q}_2 = 2.09$

$\dot{Q} = 2(\dot{Q}_1 + \dot{Q}_2)$

$\dot{Q}_2 = 46.6$ W

$\dot{Q}_1 = 2.09 \times \dot{Q}_2 = 97.39$ W

Conductive heat transfer through surface 1:

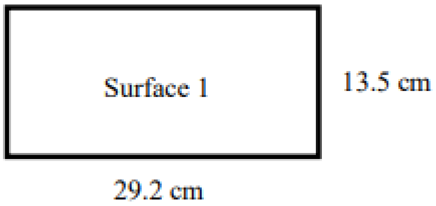

Fig.2: Side view of battery

T_s is surface temperature of profile
T_∞ = Temp of air = 30°C
U_∞ = Velocity of air = 8 m/s
Mean Temperature

T_m=35°C

Property of air 35°C from HT data book

$\rho air = 1.146\ kg/m^3$

$\mu = 18.87 \times 10^{-6}\ Ns/m^2$

As per our design the dimension of fin profile is

L=27cm

b= 5cm

t=0.3cm

Re= 121462.63 < 5 × 105

Flow is laminar

Nusselt number:

$NuL = = 0.664 \times (Re)^{0.5} \times (Pr)^{0.333}$

Hl/kair =213

h =21.37 $W/m2$

Heat transfer through convection from profile surface:

$As = 2 \times (b \times L) + (L \times t) + 2(b \times t) = 281\times 10-4\ m^2$

$\dot{Q}_{fin} = hAs\ (Ts - T\infty)$

$\dot{Q}_{fin} = 6.0$ W

No. of fins = $\dot{Q}_1/\dot{Q}_{fins} = 97.39/6 = 16.36 \sim 16$

The gap between two fins is 0.58 cm

Conductive heat transfer through surface 2

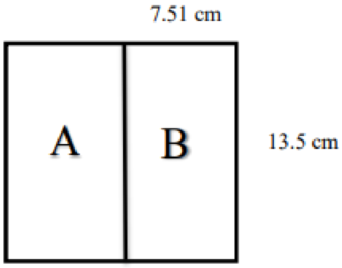

Fig.3: Front view of battery

The outer surface temperature of casing should be 45°C

So, assume T_b=45°C

The Q2 is divided into two parts of equal area

$Q_a = Q_b = Q2/2 = 46.6/2 = 23.3$ W

As air strike the surface and get divide in two parts

Surface B

T_∞ = Temp of air = 30°C, U_∞ = Velocity of air = 8 m/s

Surface temperature & Mean temperature of surface B is same as surface 1

T_s =40°C, T_m=35°C

Properties at 35°C are like surface 1

As per our design

L= 6.51cm, b=2 cm, t=0.3 cm

Reynolds Number (Re):

Re= $\rho u_\infty L/\ \mu$= 31628.87 < 5 × 105

Flow is laminar
Where,
ρ air = 1.146 kg/m^3
$Pr = 0.7\ u$=18.87 × 10-6 Ns/m^2
$k\ air$ = 0.0271 W/mK
Average Nusselt number =Nul=$0.664(Re)^{0.5}\times (Pr)^{0.333}$

Hl/kf= $0.664(31628.87)^{0.5}\times (0.7)^{0.333}$ =104.86

h = 43.65 w/m^2k

$A_S=2(6.51\times2) +2\times (0.3\times2) + (0.3\times6.51) = 29.193\times10^{-4}$

$Q_{conv\ (fin)}$ =1.27 W

No of Fin = $\dot{Q}_B/\dot{Q}_{fin}$ = 23.3/1.27 =18

The gap between two fins is 0.47cm

The total heat which is dissipated to the surrounding with the help of a fin is 288 W

Total heat dissipation from a casing without fins is calculated as 39.2 W

The effectiveness $\in = \dot{Q}_{\text{with fins}} / \dot{Q}_{\text{without fins}}$ = 288/39.2 = 7.3

4. DESIGN METHODOLOGY

We have considered Magnus EX electric vehicle battery as our project model since it is available, having detachable battery and was having scope for battery cooling using fins. We have finalized the following methodology:

1) To select various design parameters which are needed to make the basic design of fins and it should be selected in such a way that it should improve the battery life and performance of vehicle.

2) We have first designed the battery of magnus EV by ourself because the internal resistance of the cell and cell composition was unknown to us due to secret threads. we knew that the battery is having 60 V 38 Ah output so we considered the prismatic cells (3.7 V 15 Ah each) and arranged it in such a manner that 16 cells are connected in series and 2 such sets are arranged in parallel to from 16S2P configuration. Afterwards we proceeded for heat generation and calculations for fin design

3) To design a cad model in Fusion 360 computer aided design (CAD) modeling software as per the selected parameters. The created design should be simple in construction.

4) To perform the analysis of the casing (with fins) and (without fins) with selected materials as per the material study done. The material study to be done considering the requirements for manufacturing of the fins and casing.

5) Comparative study of results that we got in the ICEPAK analysis of basic design of casing with fins and finalize a suitable material for the casing and fins so as to improve its performance and to achieve the goal of faster heat dissipation.

6) The final step is to check the sustainability of the design under the action of applied boundary conditions and to check that it is properly designed or not and make a conclusion for the results we got in ICEPAK analysis of the design.

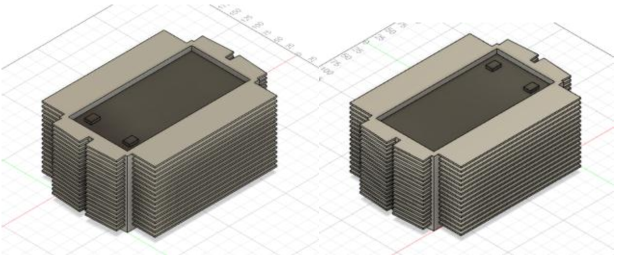

Fig.4: Basic design of casing with fins

5. ANALYSIS:

Ansys software is used for analysis and to be more precise ICEPAK analysis is done on both the geometries of casing i.e., (with fins) and (without fins). ICEPAK analysis is basically done on the geometries which are subjected to forced convection. ANSYS Icepak is a software tool used for thermal analysis and design of electronic systems, including printed circuit boards (PCBs), electronic components, and other electronic devices. The "Facet Quality" feature in ANSYS Icepak refers to a specialized meshing algorithm used to create high-quality meshes for complex geometries, such as those found in electronic systems.

The Facet Quality algorithm is based on the "faceted" or "polyhedral" meshing approach, which involves dividing a 3D geometry into a set of flat, planar surfaces or facets. This approach can be particularly useful for modeling complex shapes and irregular geometries. The Facet Quality algorithm ensures that the facets are properly aligned and have the correct orientation, which helps to improve the accuracy and efficiency of thermal simulations.

Analysis is carried out in such a manner that the geometry is simplified to ICEPAK geometry by ICEPAK simplify command, facet quality is set to high as it denotes the technique of dividing a complex subject into its several parts. Further the geometry is enclosed in a cabinet and then applied the different conditions and parameters on them like ambient temperature, velocity of moving air, assigning the suitable material and also by feeding the overall heat loss of the battery in the surrounding. We have simulated the geometry from 0sec up to 1800sec keeping the timestep and no of iterations as 5. For meshing cutcell meshing is done taking the element size as 3 and then we run the solution to obtain the results. Analysis of the two geometries are done and compared with each other to find the output of both the models using the fins and without using fins and effectiveness is also evaluated.

Type of Mesh	3D Cutcell Mesh
Element Size	3 mm
Number of Nodes	3803497
Number of Elements	3615718

Table 2: Information of Meshing of casing with fins

Type of Mesh	3D Cutcell Mesh
Element Size	3 mm
Number of Nodes	2283418
Number of Elements	2118266

Table 3: Information of Meshing of casing without fins

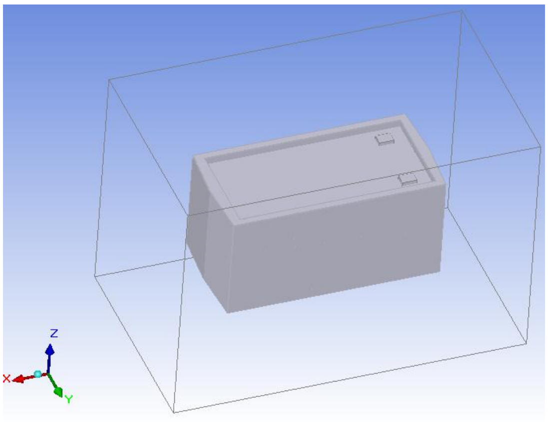

Fig.5: Meshed model of casing without fins design

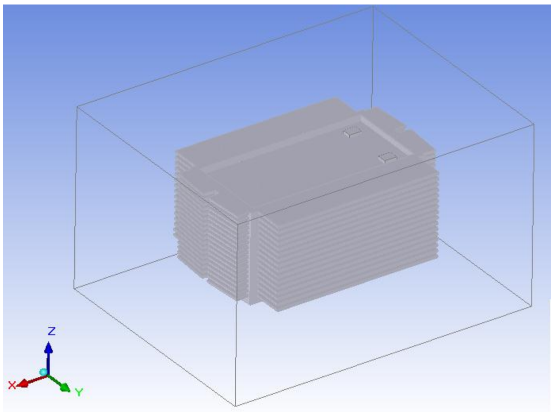

Fig.6: Meshed model of casing with fins design

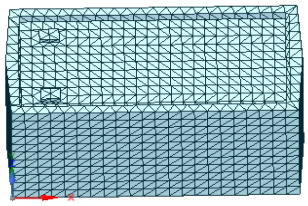

Fig.7: Facet Meshed model of casing without fins design

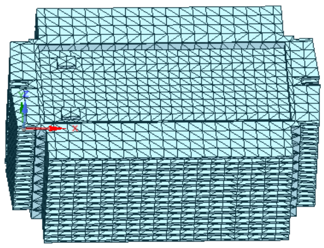

Fig.8: Facet Meshed model of casing with fins design

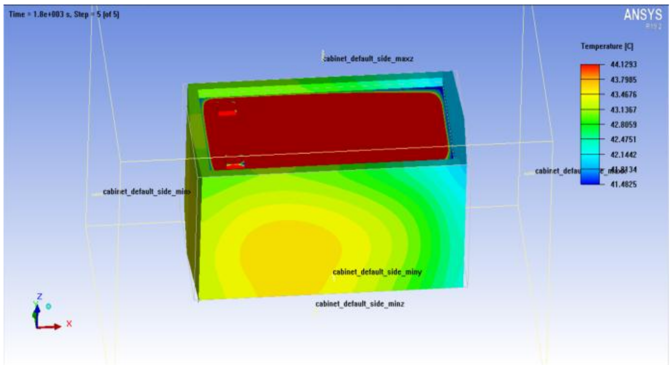

Fig.9: Temperature contour of casing without fins

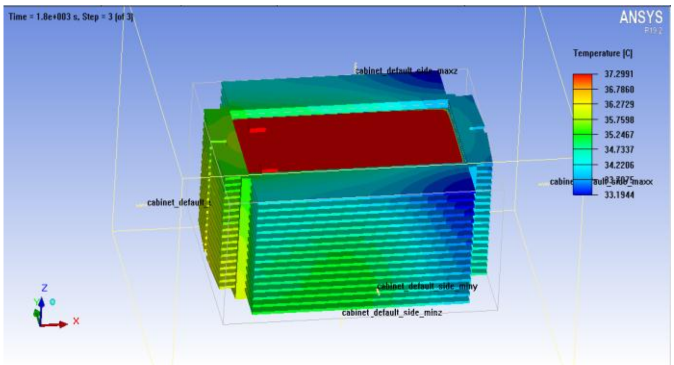

Fig.10: Temperature contour of casing with fins

6. RESULTS:

1) Heat transfer with fin = 288 W
2) Heat transfer without fin = 39.24 W
3) Heat transfer by using fins on battery casing is 7.3 times more than that of without fin on battery casing
4) The heat is not getting accumulated on battery surface with the help of using fins, hence enhancing battery lifespan.
5) Overall efficiency of vehicle is increased

MODEL	Temperature of Battery surface	Heat dissipation
Battery casing with fins	37	288 W
Battery casing without fins	44	39.24 W

Table 4: Result Comparison Table

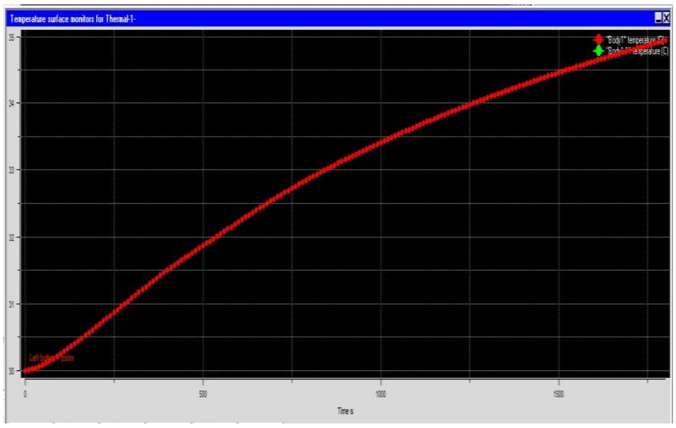

Fig.11: Temperature contour of casing with fins

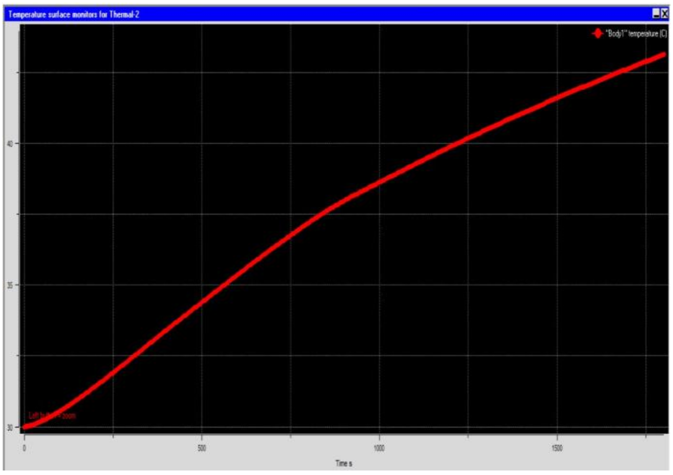

Fig.12: Temperature contour of casing without fins

7. CONCLUSION:

The temperature variation depends on surrounding air temperature, c rate and many other parameters. The most weighted parameter for temperature variation found out to be cell capacity. In this work, we identified differences between the suggested battery casing with fins design and without fins design. Both of the suggested cooling fins design and without fins design have undergone analysis and simulation. Results from the simulation process were compared. Comparing the proposed designs to the current design, the proposed designs have maximum heat dissipation rate and faster cooling. This study demonstrated that cooling fins have the capability to boost the battery's useful life and performance. The objective of designing the fins on the battery casing for cooling and excellent battery performance is successfully achieved. The vehicle efficiency is increased by improving the battery life by faster cooling using fins and thus overall heat dissipation is increased. Also faster cooling rate is achieved by implementing the fin concept.

8. ACKNOWLEDGEMENT

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