

HEV Battery Pack Thermal Management Design and Packaging Solutions

Sury Janarthanam, Sarav Paramasivam, Patrick Maguire, James Gebbie, and Douglas Hughes
Ford Motor Company

ABSTRACT

Hybrid Electric Vehicles (HEV) utilize a High Voltage (HV) battery pack to improve fuel economy by maximizing the capture of vehicle kinetic energy for reuse. Consequently, these HV battery packs experience frequent and rapid charge-discharge cycles. The heat generated during these cycles must be managed effectively to maintain battery cell performance and cell life. The HV battery pack cooling system must keep the HV battery pack temperature below a design target value and maintain a uniform temperature across all of the cells in the HV battery pack. Herein, the authors discuss some of the design points of the air cooled HV battery packs in Ford Motor Company's current model C-Max and Fusion HEVs. In these vehicles, the flow of battery cooling air was required to not only provide effective cooling of the battery cells, but to simultaneously cool a direct current high voltage to low voltage (DC-DC) converter module. In addition to the fundamental heat transfer goals, the design team overcame package challenges on cooling air flow distribution to both cell arrays and DC-DC convertor and air rush concerns. This paper describes the work the team completed to successfully balance the design requirements.

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INTRODUCTION

Ford's current model C-Max and Fusion hybrid battery packs are built with 76 Lithium-ion cells that are wired in series and are nearly identical in their design. The battery pack provides 1.4kWh of energy and has a 35kW charge and discharge capability. It also houses a 165 Amp DC-DC convertor. All of the battery cells and the DC-DC convertor are cooled by a shared air cooled system.

HV battery packs can be utilized efficiently only when they are operated within a specific temperature range. At higher temperatures the battery life span is reduced, battery performance declines and efficiency decreases. The battery cooling system must therefore be designed to keep the lithium-ion cell pack operational temperature below a certain threshold while at the same time maintaining uniform air flow across the battery cells and providing sufficient cooling to the DC-DC convertor. While meeting the primary purposes of cooling battery cells and the DC-DC convertor, the cooling system had to be designed to meet luggage space and vehicle cargo requirements. Additionally, vehicle cabin and climate control performance could not be compromised and air handling/air flow Noise, Vibration and Harshness (NVH) had to be minimized.

This paper presents how the HV battery pack cooling system was designed and packaged to meet all thermal management functions and vehicle attribute challenges. This paper also describes the system validations that were performed utilizing Computational Fluid Dynamics (CFD) analysis and thermal measurements to obtain the optimum configurations of the cooling system on the C-Max HEV.

SYSTEM ARCHITECTURE

The high voltage battery assembly is placed behind the second row seat in the cargo area of the C-Max HEV as shown in [Figure 1](#).

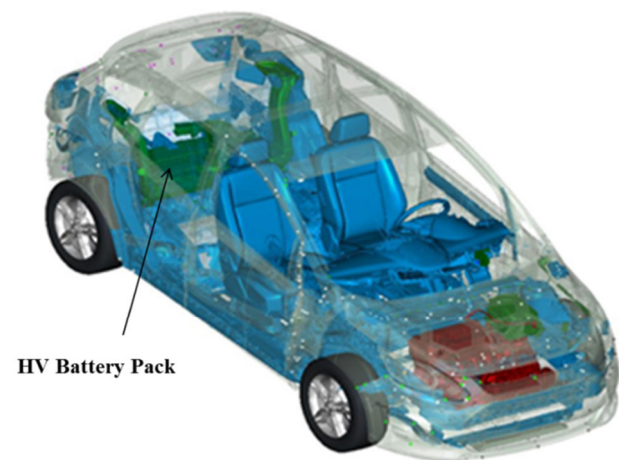


Figure 1. HV Battery Pack Location

Cabin climate air is used for battery thermal management. A single fan assembly which can provide required air flow is packaged at the outlet and is used to cool both the battery pack cell arrays and DC-DC convertor. [Figure 2](#) shows the general layout of the grille openings, inlet ducts, battery pack, DC-DC assembly and cooling fan in the C-Max vehicle. Cooling ducts inlet opening area, duct sizing, ducting interface, and grille pattern were all designed to minimize the NVH impact resulting from air inlet noise at the duct inlets.

Cooling ducts were correctly sized to minimize the pressure drop along the cooling path, which has the benefit of allowing a lower fan speed to drastically reduce the interior noise.

For the C-Max battery cooling system, cabin air is drawn in from both sides of the vehicle through equally sized ducts. This allows the cabin interior climate equilibrium to be maintained and reduces any thermal impact to passengers. The cooling ducts are designed and packaged to provide 70% of air flow to the battery pack cell arrays and 30% of the air flow to the DC-DC convertor¹. All the air flow from right side ducting is directed solely to the battery pack, whereas the left side ducting is designed to provide cooling air to both battery cell arrays and the DC-DC convertor.

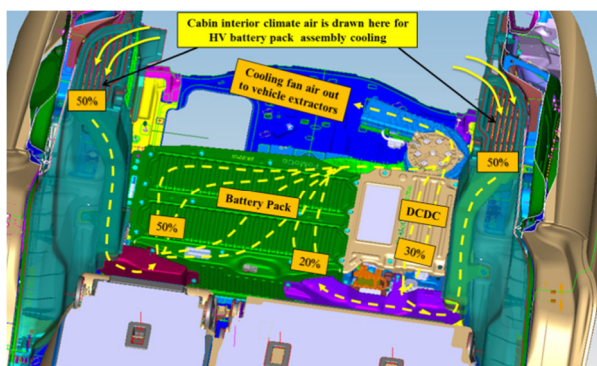


Figure 2. General Layout of HV Battery Pack Cooling System

Additionally, the thermal management system is designed to attenuate any NVH resulting from cooling fan operations and to reduce its impact on vehicle cabin climate control. The cooling fan is well covered and packaged under the cargo management load floor, behind the battery enclosure. The fan's chute or outlet duct length and opening is designed to minimize air outlet noise. A virtual ducting path was created within the cargo management box and rear body panel for the cooling fan exhaust flow path². The ducts route the exhaust air to the vehicle extractors which are located on both sides of the vehicle.

Exhausting all of the outlet air through the air extractors can lead to a significant temperature and humidity load on the vehicle climate control system. To reduce this load, the battery thermal system was designed to promote some mixing of the battery exhaust air with the cabin climate air. The virtual duct formed by the cargo management system and the vehicle body structure ends at the inner trim area, where the flow path is open to both of the air extractors and to the open area/cavity between the outer body panel and inner trim panel where part of the battery cooling exhaust air is recirculated back into the vehicle cabin environment. This design reduced the impact on the cabin climate system while drawing required air for the battery cooling from the given cabin climate air volume. Figure 3 shows the virtual ducting path for the cooling fan exhaust and mixing area between the two body panels.

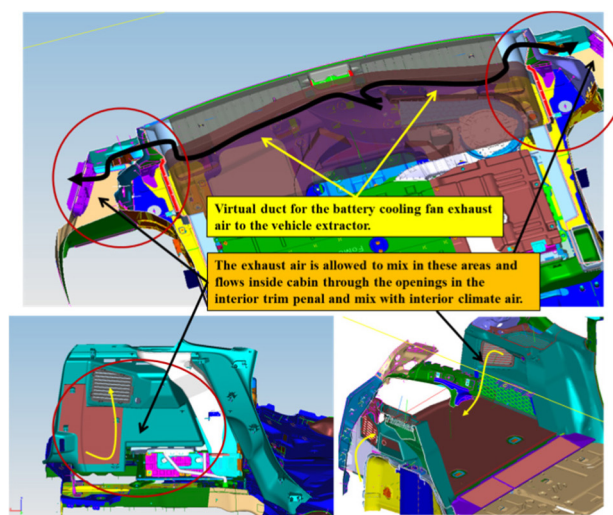


Figure 3. Battery Cooling Air Exhaust Path

The entire virtual ducting path is sealed to eliminate air leakage and associated NVH. The air inlet duct interface with inlet grille areas and ducting interface with battery pack assembly are sealed to prevent any micro-recirculation of exhaust air into the battery air inlet.

HV Battery Pack Assembly Design

The battery pack assembly is designed to provide uniform air flow through all cells in the pack as well as to provide the required air flow to the DC-DC convertor. The general layout of all the components in the battery pack assembly is shown in the figure 4. The entire 76 lithium-ion cells are grouped into two arrays connected in series, one cell array in the front and the other cell array in the back. The DC-DC convertor is housed next to the battery cell arrays. Both the cell arrays and the DC-DC convertor are secured to the battery tray and enclosed with an outer sheet metal enclosure. The battery enclosure also has the air inlet ducting interface at the front, and cooling fan interface at the rear. A jumper duct is packaged between the DC-DC convertor outlet port and cooling fan inlet port.

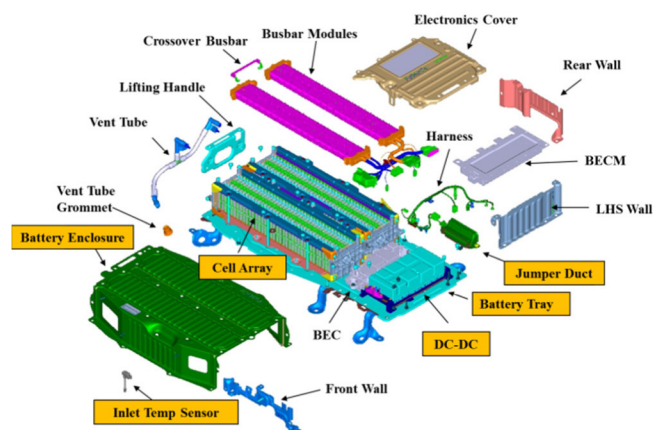


Figure 4. Layout of Parts in the Battery Pack Assembly

The Battery Electronic Control Module (BECM) controls the cooling fan operation based on inputs from the inlet temperature sensor inside the battery pack assembly and battery operating conditions.

¹. US Patent # 9,016,412 B2

². US Patent # 9,302,573 B2