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(RESEARCH ARTICLE)

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Innovative approach to develop a thermal management system for a battery electric vehicle

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Abstract

Nowadays all the automotive OEMs were investing huge amount of dollars to develop an innovative technology to handle the thermal management system of their battery electric vehicle (BEV) and hybrid electric vehicle (HEV) . Lots of techniques were used to develop this thermal management system (TMS) by investing huge amount of man hours . In this paper an innovative is handled to understand the available available possible ways to achieve a cost optimized TMS for a HEV and BEV. This is a very basic, but efficient methodology which leads to provide an enhanced system to balance the cost and achieve the customer requirements. The pugh DFSS methodology is used to compare,analyze and evaluate using the simulation techniques. Going forward this proven solution can be implemented in the real time vehicles.

Keywords: Battery Electrical Vehicle; Thermal Management System; Design for Six Sigma; 1D Simulation; Cooling System; Battery Cooling

1. Introduction

The components in a hybrid electric vehicle (HEV) powertrain include the battery pack, an internal combustion engine, and the electric machines such as motors and possibly a generator. These components generate a considerable amount of heat during driving cycles [1] . BEV in particular the battery pack is the key contributor in generating the heat if it doesn't have a proper thermal management system . By properly managing the thermal system the battery efficiency and life time will be increased.

1.1. Structure of HEV PT TMS

The proposed thermal management aims to address the heat removal task for main components in the HEV powertrain, including the battery pack, electric motors and the internal combustion engine. The battery pack in this study is equipped with an air conditioning system for active air cooling. The electric motors and internal combustion engine are cooled by circulated coolant. The thermal models of each component are introduced in this section.

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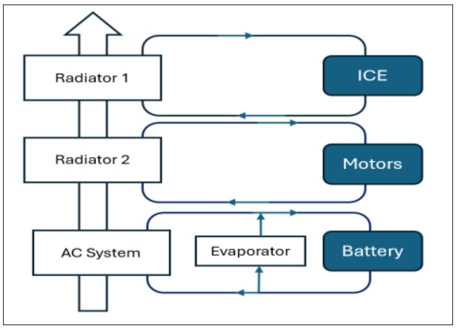

Figure 1 Simplified HEV Powertrain TMS

The structure of the hybrid electric vehicle (HEV) indicates the three level of cooling system.

- Internal Combustion Engine (ICE)
- Motor Cooling
- Battery System

A wide variety of innovative technologies, aimed at reducing vehicles fuel consumption and CO2 emissions according to the requirements of regulatory agencies , are under investigation nowadays. It is clear that CO2 reduction within the limit of 95 g/km needs the concurrent contribution of improvements in several different fields [, which include engine options , transmission, hybridization and others Among these contributions, thermal management plays an important role as significant reduction in CO2 emissions can be obtained at very low cost with respect to the other technologies [2]

A variety of electric motor thermal management methods are summarized in Figure 1 including air, liquid, heat pipes, and hybrid cooling. Air cooling is straightforward and offers a simple structure but the cooling performance may not be sufficient. Moreover, a cooling fan is usually linked to the motor shaft which consumes energy and cannot be directly controlled. Liquid cooling is effective; however, it consumes energy to run the coolant pump and radiator fan. On the other hand, liquid cooling adds more weight and complexity due to the cooling lines [3]

Next is the battery thermal management system (BTMS) which is considered a the heart of this paper . The ideology is to present the importance of using the DFSS methodology in the critical BTMS to consider all the possible control factors , noise factors involving the ideal model to have an optimal design which provides an improved efficient design .

2. Literature Review

An Initial research has been conducted to understand the background of the battery electric Vehicles. Starting from the power and energy of electric propulsion [4] . Along with the power output versus the energy output of the given battery storage device, the structure of the BEV circuit involving the electric motor ,on-board charger and the battery pack [5]. Various published papers were analyzed to understand the basics of the battery electric vehicle ,their cooling methods , process based approach in designing the cooling system using the DFSS methodologies . From this technical review can able to the effectiveness of the 1D model , simulation and the importance of correlation with the actual vehicle data .

In the paper titled "Simulation and Optimization of Lithium-Ion Battery Thermal Management System Integrating Composite Phase Change Material, Flat Heat Pipe and Liquid Cooling" by Qianqian Xin Et al , the thermal performance of the combined CPCM, FHPs, and liquid cooling are examined through numerical simulation compared with the schemes without combined liquid cooling techniques. Four schemes of BTMSs are proposed: Scheme 1 with CPCM cooling only; Scheme 2 with combined CPCMs and ATDPs; Scheme 3 with combined CPCMs and FHPs; and Scheme 4 with combined CPCMs, FHPs, and liquid cooling were discussed in detail which gives more possible approaches for battery cooling system

The most of the reviewed research works are highlighted throughout this paper and mentioned under the reference section.

2.1. Design For Six Sigma (L18)

Design for Six Sigma (DFSS) is a different approach to new product or process development in that there are multiple methodologies that can be utilized.

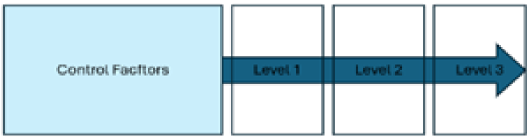

Figure 2 Control Factors

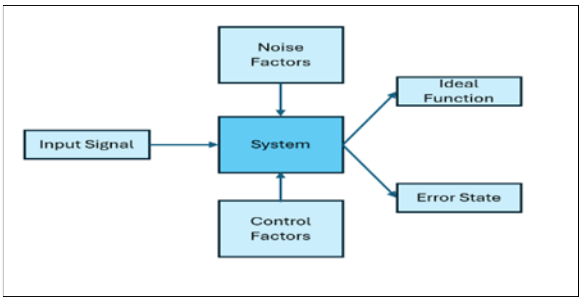

Figure 3 P-Diagram

In Figure 2 Indicated the list of control factors along with the 3 levels of control factors which involves the wide range of possible parameters. In this BTMS case it can be cold plate configuration, immersion cooling system ,mode of cooling etc.

# of Runs	Control Factors								Heat Shield Surface Temperature										
									N1 (EXH e=0.2, HS e=0.1)			N2 (EXH e=0.8, HS e=0.4)							
									725	585	425	725	585	425					
	A	B	C	D	E	F	G	H	M1	M2	M3	M1	M2	M3	Ybar	Sbar	Var	b	S/N
1.	1	1	1	1	1	1	1	1	110.4	107.3	105.0	147.7	129.4	114.8	119.1	578	165.23	0.06	-46.13
2.	1	1	2	2	2	2	2	2	106.4	105.0	103.9	118.2	113.0	108.3	109.1	578	18.61	0.02	-46.53
3.	1	1	3	3	3	3	3	3	104.5	103.9	103.4	109.4	107.3	105.4	105.6	578	3.30	0.01	-46.58
4.	1	2	1	1	2	2	3	3	109.5	106.7	104.5	149.0	131.1	114.6	119.2	578	188.41	0.07	-46.44
5.	1	2	2	2	3	3	1	1	105.8	104.5	103.4	118.1	112.8	108.0	108.8	578	20.20	0.02	-46.80
6.	1	2	3	3	1	1	2	2	103.0	102.7	102.4	105.3	104.3	103.5	103.5	578	0.78	0.00	-47.12
7.	1	3	1	2	1	3	2	3	110.4	106.9	104.3	149.2	131.2	115.1	119.5	578	185.23	0.07	-46.19
8.	1	3	2	3	2	1	3	1	105.8	104.2	103.0	119.2	113.4	108.1	108.9	578	24.25	0.02	-46.59
9.	1	3	3	1	3	2	1	2	103.8	103.2	102.6	109.2	106.9	104.8	105.1	578	4.02	0.01	-46.64
10.	2	1	1	3	3	2	2	1	111.4	107.1	103.8	172.3	145.8	121.2	126.9	578	460.26	0.10	-46.86
11.	2	1	2	1	1	3	3	2	109.4	105.7	102.8	146.5	129.0	114.7	118.0	578	172.94	0.06	-46.28
12.	2	1	3	2	2	1	1	3	101.3	100.1	98.5	113.1	108.4	104.0	104.2	578	19.86	0.02	-47.06
13.	2	2	1	2	3	1	3	2	111.8	107.3	103.9	175.8	147.7	122.0	128.1	578	505.79	0.10	-46.82
14.	2	2	2	3	1	2	1	3	109.8	105.7	102.5	149.8	131.3	115.4	119.1	578	201.87	0.07	-46.25
15.	2	2	3	1	2	3	2	1	101.2	99.7	98.4	112.9	108.3	103.9	104.1	578	20.08	0.02	-47.12
16.	2	3	1	3	2	3	1	2	112.7	107.7	103.8	172.1	146.1	122.7	127.5	578	446.90	0.10	-46.78
17.	2	3	2	1	3	1	2	3	108.2	104.8	102.1	148.5	130.4	114.8	118.1	578	203.82	0.07	-46.70
18.	2	3	3	2	1	2	3	1	98.7	98.0	97.3	105.7	103.2	100.7	100.6	578	7.25	0.01	-48.11
																	Averages=	0.05	-46.72

Figure 4 Sample L-18 Array

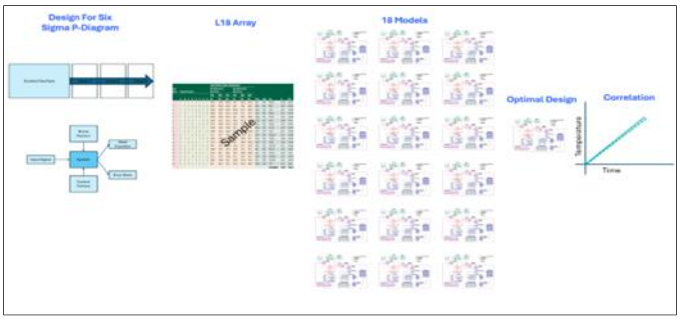

Figure 5 Process Summary

P-Diagram in Figure 3 and sample L18 array is shown in the Figure 4. From which the list of control factor combinations can be observed and understood.

The process involves the with the control factors ,L18 [6] arrays generation,18 1D Models (Amesim [7]), Simulation , from the L18 array achieving the Optimal design and followed by the correlation of 1D Simulation results with the actual vehicle test data .

The core idea of this paper is to emphasize the steps involved in the designing of a battery thermal management system from selecting the control factors from the start to the maximum value whereas the real time scenario values will be covered within this range (level1,2,3).

After that the L18 arrays give a combination of control factors, from which total of 18 one dimensional models were developed. Based on the simulation results and the comparison an optimal design factors combination is achieved to develop an optimal model.

This optimal model is simulated from which the battery coolant inlet temperature and the battery cell temperatures were measured. In general, already we had the basic 1D model simulation results which are far from the target and the actual vehicle test values. By implementing this DFSS methodology the improvement in correlation is observed in the optimal 1D design.

3. Summary

It Is evident that implementing the DFSS methodology for modelling a cooling system will provide a model which has the similarity in results compared to actual vehicle results within error of 5 % [8]

Table 1 Results

Sl.#	**Items**	**Target °C**	**1D Simulation**	**Improved 1D Simulation**	**Vehicle Test**	**%**
1	Battery Coolant Inlet Temperature	70	72	69	70	1.2
2	Battery Cell Temperature	35	37	33.5	35	4.2

An integrated approach which combines analysis of the effect of simultaneous variations in model input parameters on component or system temperatures. The sensitivity analysis can be conducted by varying model input parameters using specific values that may be of interest to the user. The alternative approach is to use a structured set of parameters generated in the form of a DFSS DOE matrix [9]

In additional to the literature review section in this paper more an in-depth information about the DFSS is discussed in this section.

Design for Six Sigma (DFSS) methodology can be applied to the vehicle development process in order to provide significant results in terms of quality improvement, cost optimization and reduction of development timing. The Design for Six Sigma methodology, which is originated and structured starting from Six Sigma, brings an approach and a group of tools dedicated to the development of products, being unique in its application, because it aims to cooperate in a direct way with the new needs of VDP [10]

Six sigma applied to problems solutions follows the DMAIC framework like a common framework in a great part of companies. However the design for six sigma has different frameworks all with the same objective even though phase quantity and names vary. In this paper it was used IDDV as framework . In the figure 6 . it is shown the DFSS framework. .The proposal of identify phase to identify the real customer needs . In the define phase is to translate the results of the identify phase into measurable items , the CTQ.In develop phase the concept that meets the customer needs as generated .There are two important task in this phase the divergent activity and convergence ideas.

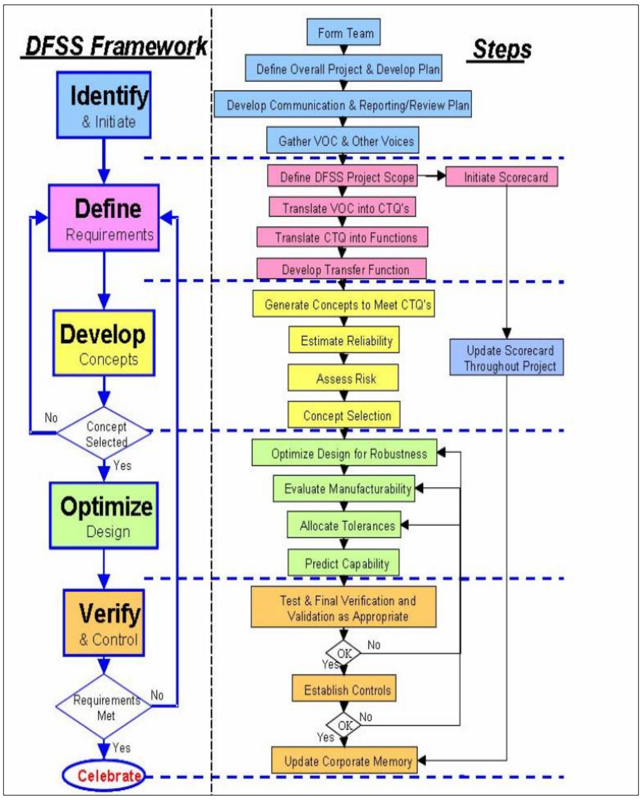

Figure 6 Process Summary [11]

In optimize phase from the defined control factors an optimal design is achieved. This is the most important phase in which the optimal design which is the most important one in the overall design process. Finally in the verification phase the achieved optimal design is verified. [11]

Diverting the focus back to our paper From the table 1, it is clarified that both the items battery coolant inlet temperature and the battery cell temperature measured from improved 1D model is in good correlation with the actual vehicle test data [12]. Furthermore, the co-simulation extended to HIL by coupling can give an higher accuracy [13].

Definitions/Abbreviations

- BTMS Battery Thermal Management System
- TMS Thermal Management System
- HEV Hybrid Electric Vehicle
- BEV Battery Electric Vehicle
- 1D One Dimension
- CPCM Composite phase change material
- FHP Flat Heat Pipe
- ATDP Aluminum Thermal Diffusion Plates
- VDP Vehicle Development Process
- CTQ Critical To Quality

4. Conclusion

In this paper DFSS methodology was used to develop an optimal model from which an improved combination of control factors were achieved to design a better performing battery thermal management system. The performance of the virtual model is correlated well with the actual test results which shows a acceptable difference of 5 % . This rigid model can be used as baseline to do multiple changes in the system without developing a proto model. In general this methodology provides an innovative approach to design an optimal cooling system for the BEV , which is the fast emerging trend in automotive world.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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