Helios

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'High Energy cell target specification for EV, PHEV and HEV-APU applications'

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Abstract:

This paper has defined a set of battery specifications derived from system level parameters of EV, PHEV and HEV-APU applications.

Because of project budget and timescale limitations it was necessary to manufacture and test only one cell type for each of the four cell chemistries and therefore to arrive at just one cell specification. The application for PHEV and HEV-APU was chosen over EV as being most relevant to the industry.

The target specification is used to build full size cells with the different cell chemistries under consideration in the HELIOS project. The target cell specification has included the energy and power requirements as well as cycle and calendar life.

1. Methodology

The cell target specification was developed top down from the vehicle requirements via the battery system requirements to the cell level requirements. Since three different applications are targeted (EV, HEV and HEV-APU), it was necessary to follow three parallel paths, one for each application type. In conjunction with the targeted vehicle mileage and energy consumption, the battery system cycle life or energy throughput was calculated. This calculated / simulated power, energy and life requirements were added with other typical performance values such as power vs. temperature, voltage range etc. gained from experience with electrically propelled vehicles to complete the battery system specification.

A common system specification that matched the requirements of the OEM's interested in the specific application was compiled. Based on the common specifications, the work derived the cell level requirements. The first step was to determine the necessary cell count or Battery Scaling Factor (BSF). It is important to match the system voltage for the integration of a battery system into a specific application EV or PHEV. So, considering the voltage range of the four different chemistries used in HELIOS (NCA/graphite, NMC/graphite, LFP/graphite, Mn-spinel oxide/graphite), the number of cells was calculated. Then, a "cell capacity calculator" tool was used to calculate the resulting capacity for a 1P (all cells connected in series) configuration in the system. The tool considers the usable energy, the applied SOC (state of charge) window as well as the cell count, which was different for the specific chemistries, especially for the LFP type. At this time, also the power and energy requirement for the HEV-APU application were entered into the cell target specification development.

After the necessary capacity was calculated and the BSF was determined, it was possible to calculate the power, energy and cycle life requirement. However, in order to calculate the mass and volume requirement at cell level, a different scaling factor was needed. In a survey between the OEM's the typical scaling factors for mass and volume was evaluated. For an EV type application typically 70% of the system mass and 60% of the system volume are allocated to the cells. For a PHEV application, which is smaller compared to an EV application, more mass and volume is used up for the system overhead such as electric/electronics and battery tray. Therefore, the scaling factor for the PHEV application was considered as 62% of the mass and 55% of the volume.

The cell level specification could then be established. Since the system level requirements for EV, PHEV and HEV-APU applications differ especially in the power to energy ratio, **it was only possible to simplify to two sets of cell target specifications.** Also, the duration of peak power differed for the two sets of specifications. Investigating typical peak power behaviour of Li-Ion cells, it was possible to estimate the peak power for 15s, 30s and 45s. This allowed the comparison of the original peak power requirement for EV and PHEV / HEV-APU applications.

Type	EV cell	EV cell 45Ah	PHEV cell
Peak power 15s			900 W
Peak power 30s	1000 W	645 W	850 W
Peak power 45s	750 W	482 W	
Specific power 30s	717 W/kg	717 W/kg	1104 W/kg
Specific energy	179 Wh/kg	179 Wh/kg	150 Wh/kg
P/E ratio	4	4	7
Mass	1400 g	900 g	770 g

However, it became clear that only **one type of cell could be manufactured and tested as a full size cell within the HELIOS project time and budget**. **Therefore it was necessary to select one type of cell specification.** The target specification that seemed better suited for manufacturing the cells within the given boundaries of the HELIOS project was chosen.
The EV type cell specification needed to be scaled down from a ca. 70Ah cell to a ca. 45Ah cell. However, it still would require a very high loading of the electrodes making it difficult for some of the chemistries to produce the electrodes. The PHEV type requires thinner electrodes and should be easier to manufacture.
Therefore it was decided to use the cell target specification for the PHEV/ HEV-APU type application for manufacturing the full size cells. One drawback of course is that the PHEV / HEV-APU type requires higher currents exceeding some of the cell cycler's current limits. This has to be considered for the performance and ageing test procedures and the allocation of test benches.

For comparison purpose the USABC PHEV requirements on system level for both the 10 mile and the 40 mile PHEV were considered. These system requirements were compared with the requirements from the European OEM'S. However, the power requirements from USABC did not match with the needs for most of the PHEV and also the HEV-APU application. The energy needed was somehow in-between the 10 mile and the 40 mile requirement. The system requirement developed within HELIOS provides more details for describing the battery system performance. Also, there is no requirement on cell level available.

The EV type targets from UASBC are from the 90's and were considered outdated. So, there was no reference or state of the art document for this type of application available.

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2. Description of the results

Battery system suited for EV application

HELIOS WP3	EV requirements			
	System specification	unit	common value	comment
System Performance				@ RT
	max discharge power (peak power)	kW	75	@ 20%SoC
	duration for max discharge power (peak power)	s	45	
	continuous discharge power	kW	45	@ SoC 100%to 20%
	average power (RMS charge or discharge)	kW		
	max. regen power	kW	45	@80%SoC
	duration for max regen power	s	10	
	max. charge power (fast charge)	kW	32	
	duration for max charge power (fast charge)	min	30	
	usable energy higher than (BoL)	kWh	20	
	total energy higher than (BoL, 100%SoC)	kWh	25	
	Current			
	max regen current	A	200	
	max discharge current	A	325	
	RESS Charge/Discharge Efficiency	%	95	1C / 2C (charge/discharge)
	Power to Energy ratio	P/E	3,3	
Energy vs. Temperature behavior				
	at temperature 0℃	%	90	compared to RT @ 1C rate
	at temperature -10℃	%		compared to RT @ 1C rate
	at temperature -20℃	%	75	compared to RT @ 1C rate
Power vs. Temperature behavior (discharge)				compared to RT
	at temperature 0℃	%	65	20s pulse @ 30%SoC
	at temperature -10℃	%		
	at temperature -20℃	%	*40*	20s pulse @ 30%SoC
Power vs. Temperature behavior (charge power capability)				compared to RT
	at temperature -10℃	%	30	20s pulse @ 30%SoC
Self discharge				
	in %SOC / month	%	<1	@ 35℃ w/o BMS
Voltage				
	Voltage Levels			
	max voltage	V	420	
	min voltage	V	250	
Temperature				
	operating temperatures			
	min	℃	-30	
	max	℃	50	
	non operating temperatures			
	min	℃	-30	
	max	℃	65	
Lifetime				
	calendar life (@25℃)	year	> 10	35℃
	cycle life (@25℃)			
	cycle life (see EUCAR specification, 80%DoD)	cycles	3,000	35℃
	EV cycle life discharge energy throughput	kWh	60,000	
Physical Requirements				
	max. weight	kg	200	
	max. dimensions	mm		
	max. volume	l	125	

Battery system suited for PHEV application:

HELIOS WP3	PHEV requirements, only valid for passenger car; HEV-APU input is used for cell specification			
	System specification	unit	common value	comment
System Performance				@RT
	max discharge power (peak power)	kW	80	@30 %SoC
	duration for max discharge power (peak power)	s	15	
	continuous discharge power	kW	40	@ SoC 80%to 30%
	average power (RMS charge or discharge)	kW		
	max. regen power	kW	52	@80 %SoC
	duration for max regen power	s	15	
	max. charge power (fast charge)	kW	18	uo to 80 %SoC
	duration for max charge power (fast charge)	min	25	
	usable energy higher than	kWh	7	
	total energy higher than	kWh	10 - 12	
	Current			
	max regen current	A	220	
	max discharge current	A	350	
	RESS Charge/Discharge Efficiency	%	90 - 95	1C / 2C (charge/discharge)
	Power to Energy ratio	P/E	7	
Energy vs. Temperature behavior				
	at temperature 0℃	%	90	compared to RT
	at temperature -10℃	%		compared to RT
	at temperature -25℃	%	75	compared to RT
Power vs. Temperature behavior				
	at temperature 0℃	%	65	compared to RT
	at temperature -10℃	%		compared to RT
	at temperature -25℃	%	40	compared to RT
Self discharge				
	in %SOC / month	%	<1	@ 35℃ w/o BMS
Voltage				
	Voltage Levels			
	max voltage	V	410	
	min voltage	V	250	
Temperature				
	operating temperatures			
	min	℃	-30	
	max	℃	50	
	non operating temperatures			
	min	℃	-30	
	max	℃	65	
Lifetime				
	calendar life	year	10 - 15	@ 35℃
	cycle life			
	cycles CD / CS	cycles	4,700 / 250,000	HEV-APU needs 10 x cycle life
	EV cycle life energy throughput	kWh	> 33,000	
	HEV cycle life energy throughput	kWh	> 12,500	
	Total energy throughput EV mode and HEV mode	kWh	50,000	HEV-APU needs 10 x cycle life
Physical Requirements				
	max. weight	kg	120	
	max. dimensions	mm		
	max. volume	l	90	

A common EV cell specification was compiled from the EV system specification applying a battery scaling factor of 100 and 110 respectively considering the different chemistries under evaluation in the HELIOS project.
The specification of the PHEV cell was derived from the system specification of the PHEV system using a battery scaling factor of 95 and 105 respectively considering the different chemistries under evaluation in the HELIOS project. In addition, the cell requirements of a cell for HEV-APU applications were integrated into the PHEV cell specification.

Both cell specifications differ mainly in usable energy and power to energy ratio (P/E).

Cell target specification for PHEV / HEV-APU type application.

The cell target specification for PHEV / HEV-APU type application is calculated for LFP and all other cell chemistries and shown in the following table:

HELIOS WP3					
	Cell specification	unit	value PHEV / HEV-APU	value PHEV / HEV-APU LFP	comment
Cell Performance					@ RT
	max discharge power (peak power)	W	**900**	814	@ 20%SoC (EV) / 30%SoC (PHEV)
	duration for max discharge power (peak power)	s	15	15	
	max discharge power (peak power)	W	850	769	
	duration for max discharge power (peak power)	s	30	30	
		W			
		s			
	specific peak power (30s)	*W/kg*	*1104*	*1104*	@ 20%SoC (EV) / 30%SoC (PHEV)
	continuous discharge power	W	425	385	
	max. regen power	W	550	498	@80%SoC
	duration for max regen power	s	15	15	
	max. charge power (fast charge)	W	200	181	
	duration for max charge power (fast charge)	min			
	usable energy higher than	Wh	75	68	
	total energy higher than	Wh	110 - 130	95 - 115	
	capacity	Ah	35 - 40	35 - 40	
	specific energy	*Wh/kg*	*135 -160*	*130 - 155*	
	Current				
	max regen current	A	220	220	
	max discharge current	A	350	350	
	RESS Charge/Discharge Efficiency	%			1C / 2C (charge/discharge)
	Power to Energy ratio	P/E	7	7	
Energy vs. Temperature behavior					compared to RT
	at temperature 0°C	%	90	90	
	at temperature -20°C	%			lower discharge rate e.g. C/2 possible
	at temperature -25°C	%	75	75	lower discharge rate e.g. C/2 possible
Power vs. Temperature behavior					compared to RT
	at temperature 0°C	%	65	65	20s pulse @ 30%SoC
	at temperature -20°C	%			20s pulse @ 30%SoC
	at temperature -25°C	%	40	40	
Power vs. Temperature behavior (charge power capability)					compared to RT
	at temperature -10°C	%	30	30	20s pulse @ 30%SoC
Self discharge					
	in %SOC / month	%	<1	<1	@ 35°C w/o BMS
Voltage					
	Voltage Levels				
	max voltage	V	4,3	3,9	
	min voltage	V	2,6	2,4	
Temperature					
	operating temperatures				
	min	°C	-30	-30	
	max	°C	50	50	
	non operating temperatures				
	min	°C	-30	-30	
	max	°C	65	65	
Lifetime					
	calendar life	a	10 - 15	10 - 15	35°C
	cycle life				
	cycle life (CD/CS)	cycles	4,700 / 250,000	4,700 / 250,000	35°C; HEV-APU needs 10 x cycle life
	EV cycle life discharge energy throughput	kWh	350	317	35°C
	HEV cycle life discharge energy throughput	kWh	135	122	35°C
	Total discharge energy throughput EV mode and HEV mode	kWh	525	475	35°C; HEV-APU needs 10 x cycle life
Physical Requirements					
	max. weight of cell	g	770	697	
	max. dimensions of cell	mm			
	max. volume	l	0,52	0,47	

3. References

USABC requirements for PHEV energy storage systems:

USABC Requirements of End of Life Energy Storage Systems for PHEVs

Characteristics at EOL (End of Life)		High Power/Energy Ratio Battery	High Energy/Power Ratio Battery
Reference Equivalent Electric Range	miles	10	40
Peak Pulse Discharge Power (10 sec)	kW	45	38
Peak Regen Pulse Power (10 sec)	kW	30	25
Available Energy for CD (Charge Depleting) Mode, 10 kW Rate	kWh	3.4	11.6
Available Energy for CS (Charge Sustaining) Mode	kWh	0.5	0.3
Minimum Round-trip Energy Efficiency (USABC HEV Cycle)	%	90	90
Cold cranking power at -30°C, 2 sec - 3 Pulses	kW	7	7
CD Life / Discharge Throughput	Cycles/MWh	5,000 / 17	5,000 / 58
CS HEV Cycle Life, 50 Wh Profile	Cycles	300,000	300,000
Calendar Life, 40°C	year	15	15
Maximum System Weight	kg	60	120
Maximum System Volume	Liter	40	80
Maximum Operating Voltage	Vdc	400	400
Minimum Operating Voltage	Vdc	>0.55 x Vmax	>0.55 x Vmax
Maximum Self-discharge	Wh/day	50	50
System Recharge Rate at 30°C	kW	1.4 (120V/15A)	1.4 (120V/15A)
Unassisted Operating & Charging Temperature Range	°C	-30 to +52	-30 to +52
Survival Temperature Range	°C	-46 to +66	-46 to +66
Max. Current (10 sec pulse)	Amps	300	300
Maximum System Production Price @ 100k units/yr	$	$1,700	$3,400