Lithium Titanate Oxide (LTO) and Supercapacitors as an Option for Hybrid Vehicles

Andrew Burke, Jingyuan Zhao, Hengbing Zhao

Institute of Transportation Studies, University of California, Davis - December 2015

Project Summary

The use of Lithium Titanate Oxide (LTO) batteries with supercapacitors in micro- and mild hybrid vehicles has been studied. The study involves vehicle simulations and laboratory tests of carbon/carbon supercapacitors and 20Ah LTO cells from EIG, Korea. Cycle testing of the LTO cells/module on a cycle to simulate their use with supercapacitors indicated that their charge acceptance was excellent even at a charging power of 2000W (500W/cell). The test data indicated that the LTO battery would be an excellent choice for micro-hybrid applications.

Simulations of micro- and mild hybrid vehicle operation have been run using lead-acid and EIG LTO battery technologies in 16V and 48V system. It is clear from the results that the LTO batteries can function well in both the micro- and mild hybrids. The LTO batteries are much smaller than the lead-acid batteries and are more efficient. The LTO batteries had an efficiency of 95-97% while the lead-acid batteries had an efficiency of 85-88%. The effect on fuel economy of the higher efficiency of the LTO batteries was not significant for either the FUDS or highway driving cycle. This was true for even the accessory load of 800W.

Test of LTO Batteries

Test Data for EIG 6Ah LTO Cell

Constant Current test

Discharge current	Ah	Time(sec)	Resistance mOhm
2A	6.05	10891.7	
3A	6.00	7204.9	
6A	5.71	3425.1	
12A	5.42	1625.1	
30A	5.18	621.5	
60A	4.90	294.1	1.0
80A	4.80	217.5	.875

Constant Power test

Discharge power	Time (sec)	Wh	Energy density Wh/kg	Power density W/kg
10w	2166.6	11.4	41.7	36.3
20w	1396.4	10.6	38.6	72.7
30w	1042.1	10.	37.9	109.0
60w	565.4	9.3	33.9	218.1
90w	388.8	8.0	29.2	327.2
120w	287.1	6.8	24.7	436.3
200w	169.2	4.3	15.8	727.2

Weight .276 kg; Calculation of the 95% efficient pulse power:
$P = .95 \times .05 \times (2.5)^2 / .001 = 297W$, $297/.276 = 1075$ W/kg

Test Data for the EIG 20 Ah LTO Cell

Constant current A	Ah	Resistance mOhm 75% SOC
4	20.9	
10	20.9	
20	20.7	
40	20.5	
100	20.3	1.2
200	20.1	1.2

Constant power W	W/kg	Wh	Wh/kg
20	31	50.3	77.5
30	46	48.6	75.0
50	77	47.3	73.0
100	154	47.2	72.8
200	309	45.6	70.4
300	463	43.3	66.8
400	617	41.2	63.6

Cell weight .648 kg;
Calculation of the 95% efficient pulse power:
$P = .95 \times .05 \times (2.5)^2 / .0012 = 247W$, $247/.648 = 381$ W/kg

Test of C/C Supercapacitors

Skeleton Technologies 3200F

Skeleton 3200F Device characteristics
Carbon/carbon with graphene, acetronitrile 3.4V
Packaged Weight 400 gm, volume 284 cm3

Constant current discharge data

Power W	W/kg	Time sec	Wh	Wh/kg	Wh/L
106	265	123.1	3.62	9.05	12.8
201	503	64.9	3.62	9.05	12.8
301	753	42.4	3.55	8.88	12.5
400	1000	31.1	3.46	8.65	12.2
500	1250	24.3	3.38	8.45	11.9
600	1500	19.8	3.3	8.25	11.6

Discharge 3.4V to 1.7V; Resistance calculated from extrapolation of the voltage to t=0
Capacitance calculated from C= I*t disch/delta from Vt=0

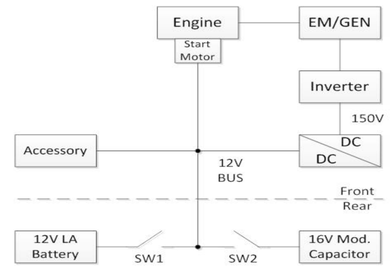
Constant power discharge data

Current A	Time sec	Capacitance F	Resistance mOhm Steady-state	RC sec
50	107.7	3205		
100	52.7	3175		
200	25.5	3178	.475	1.51
300	16.5	3173	.467	1.48
350	14	3202	.485	1.55
400	12	3168	.468	1.48

Pulse power at 95% efficiency:
$P = 9/16$ (1- eff) V_R^2/R_{ss},
$(W/kg)_{95\%} = 1730$, $(W/L)_{95\%} = 2436$
Matched impedance power: $P = V_R^2 / 4 R_{ss}$,
(W/kg) = 15, 400

Micro-Hybrid Test and Simulation

Micro-hybrid with Battery and Supercap



Battery and Supercapacitor Test Setup

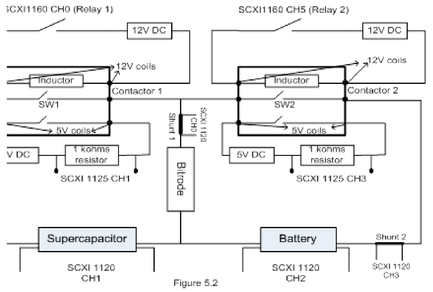
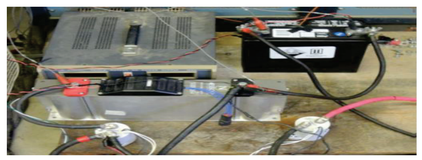


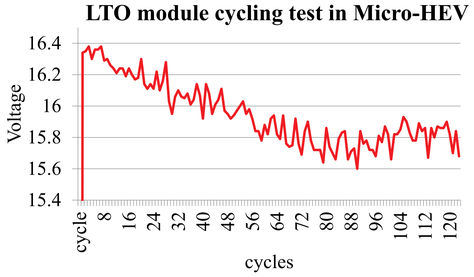
Figure 5.2



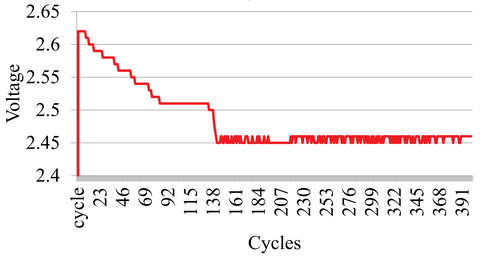
Battery Test Cycles for LTO Lithium Batteries

Lead-acid Time (s)	Lead-acid Step	Lithium LTO Time (s)	Lithium LTO Step
40	0.5kW discharging	40	0.75kW discharging
1	3kW discharging Engine start	1-2	3kW discharging Engine start
5	Rest	5	Rest
32	0.4kW charging,	9	2.0kW charging,
42	Rest	42	Rest
41.4	0.4kW charging	11	2.0kW charging
85	Rest	85	Rest
11	0.5kW discharging	11	0.75 discharging
1	3kW discharging Engine start	1-2	3kW discharging Engine start
17	Rest	17	Rest
31.6	0.4kW charging	9	2.0kW charging
120	Rest	120	Rest
14	0.5kW discharging	14	0.75kW discharging
1	3kW discharging Engine start	1-2	3kW discharging Engine start
20	Charging to $\Delta Ah = 0$	9	Charging to $\Delta Ah = 0$
5	Rest V_4		Rest V_4

LTO module cycling test in Micro-HEV



LTO cell cycling test in Micro-HEV



Hybrid vehicle simulation results using lead-acid and Lithium titanate oxide (LTO) batteries
Mid-size Passenger car: weight 1660 kg, $C_D = .3$, $A_f = 2.2 m^2$, $f_r = .009$

Mild hybrid 48V	Weight of caps kg	Energy stored Wh	Weight of the battery	Energy stored Wh	FUDS Mpg*	Highway Mpg*
Lead-acid	13	50	38	950	37.7/35.1	45.7/44.9
LTO	13	50	6	240	38.1/34.9	46.3/45.2
Micro-hybrid 16V						
Lead-acid	4	16	12	300	32.4/30.0	41.8/40.5
LTO	4	16	4	180	33.5/30.2	41.6/40.7
Conventional vehicle					26	37

* mpg accessory load 400W/800W

Conclusions

- ❑ LTO batteries are well suited for use with supercapacitors in micro-hybrid vehicles.
- ❑ The power capability and long cycle life of LTO batteries are ideal for the HEV application.
- ❑ The combination of LTO batteries and supercapacitors results in very low losses (round-trip efficiency 95%) and maximum fuel economy improvement.

Contacting the Authors:
Andrew Burke afburke@ucdavis.edu Hengbing Zhao *hbzhao@ucdavis.edu*

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