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Development of Formula Student Electric Car Battery Design Procedure

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Abstract

One of the most important parts of a Formula Student Electric race car is a battery pack, which includes accumulators and a battery management system. Difficult operating conditions in a racecar require careful approach to battery pack design, from choosing accumulator cells to mathematical modeling. The developed design procedure allows choosing an optimal battery pack design based on given initial parameters

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Keywords: battery pack; electric race car.

1. Introduction

Formula Student Electric is a part of Formula Student international intercollegiate competition, aimed at design and fabrication of electric race car by students. This competition promotes the use of new technologies and the practical application of research findings to provide the best vehicle performance. All race cars must fulfill a set of rules and pass technical examination before participating in the competition. Participation and especially winning in such contest accelerates the development of science and significantly increases the university's status, so universities are interested in building successful teams.

One of the major components of the race car is a battery pack - rechargeable battery with a control system. Initial parameters for the development were taken from the Formula Student 2015-2016 rules (which are updated every 2 years) and presented in Table 1.

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Additional limitations, explanations and permitted types of battery cells are described in detail in the competition rules [1].

Table 1. Initial parameters for the battery pack development.

Parameter	Value
Battery power limit, kW (P_{Bmax})	80
Battery voltage limit, V (U_{Bmax})	600
Battery segment voltage limit, V (U_{Smax})	120
Battery segment energy limit, MJ (E_{Bmax})	6

2. Task formulation

To fulfill the requirements of the regulations the battery pack structure shown in Fig. 1 has been developed. It is expedient to choose the powertrain voltage within the range of 300V. Such voltage will be able to provide the required output power of 80 kW with a relatively small current (up to 270A) without the excessively complex battery management system.

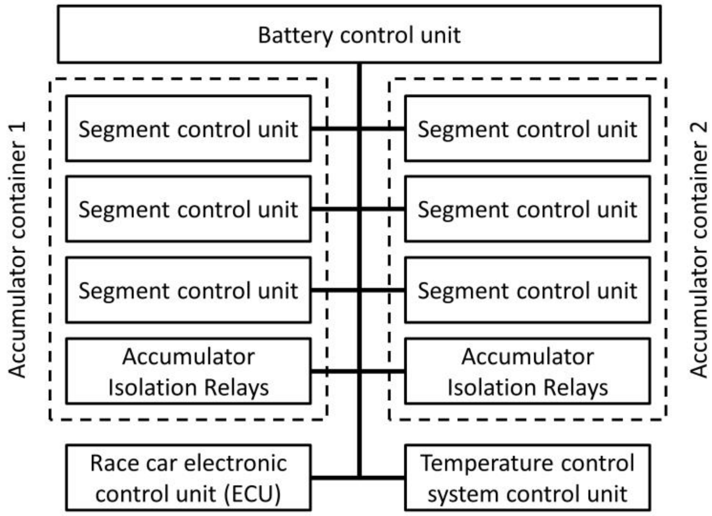

Fig. 1. Battery pack structure.

Battery pack consists of six segments connected in series and united by a single data bus with the drive control unit. Electronic control unit of the race car is also connected to the data bus. ECU processes the information and controls traction motor controllers. Accumulator Isolation Relays serve to breaking the electric circuit of pack in the case of crash, short circuit, overheating and other emergencies. To maintain a constant operating temperature of the battery, temperature control system is used, and its elements (fans, air dampers, etc.) are also connected to the data bus.

In order to obtain the optimum volumetric and gravimetric energy characteristics of the pack it is necessary to conduct the calculation and selection of the type, number and connection scheme of battery cells in the pack. Mathematical and computer modeling also useful in the design process. [2-5]

3. Development of the design procedure

The developed design procedure includes the following steps:

1. Building a database of the following characteristics of rechargeable cells available at the market:

- Cell voltage, V (U_0)
- Cell maximum voltage, V (U_{max})
- Cell capacity, Ah (C_0)
- Cell mass, kg (m)
- Cell volume, m^3 (V)
- Peak discharge current, A (I_{max})

2. Calculation of the following cell parameters:

- Cell energy, kWh (E_o)
- Maximum output power, kW (P_{max})
- Volumetric energy density, kWh/m^3 (E_v)
- Gravimetric energy density, kWh / kg (E_g)

3. Calculation of following battery parameters:

- Maximum number of serial cells limited by voltage, pieces. (N_{Umax})
- Maximum number of serial cells limited by power, pieces. (N_{Pmax})
- Number of serial cells, pieces (N_{SE})
- Number of parallel segments, pieces (N_{PS})
- Number of serial segments, pieces (N_{SS})
- Energy of a single segment, kWh (C_S)

4. Final parameters of the battery that satisfies these conditions:

- Battery voltage, V (U_B)
- Battery maximum voltage, V (U_{Bmax})
- Total number of cells in the battery, pieces (N)
- Total mass of cells in the battery, kg (m_B)
- Battery energy, kWh (C_B)

Following equations are used to calculate the parameters of the cell on the second stage[6]:
Cell energy in kWh, according to FSAE Rules:

$$E_o = C_0 \cdot U_{max} \tag{1}$$

Maximum output power:

$$P_{max} = U_0 \cdot I_{max} \tag{2}$$

Volumetric energy density:

$$E_v = \frac{E_o}{V} \tag{3}$$

Gravimetric energy density:

$$E_m = \frac{E_0}{m} \tag{4}$$

The third stage is targeted on determining the number of segments and their connection scheme in order to achieve optimal parameters. Maximum number of serial cells limited by voltage is determined by the ratio of the maximum segment voltage to the maximum cell voltage:

$$N_{Umax} = U_{Smax} / U_{max} \tag{5}$$

Maximum number of serial cells limited by power is determined by the ratio of maximum segment energy in kWh to the single cell energy:

$$N_{Pmax} = E_{Bmax} / E_0 \tag{6}$$

The number of serial cells is determined from the maximum battery voltage:

$$N_{SE} = U_{Bmax} / U_{max} \tag{7}$$

The number of parallel segments is determined from the maximum battery output power:

$$N_{PS} = \frac{P_{Bmax}}{U_{max} \cdot N_{SE} \cdot I_{max}} \tag{8}$$

The number of serial segments should be minimal with the given restrictions on the maximum voltage and the maximum energy:

$$\begin{cases} N_{ss} = \dfrac{N_{SE}}{k}; \\ k \le N_{Umax}; \\ k \le N_{Pmax}; \\ n_{ss} \to min. \end{cases} \tag{9}$$

The energy of a single segment is determined by the product of the number of elements in the segment (k) and the single sell energy:

$$C_s = k \cdot C_1 \tag{10}$$

The last stage determines final parameters of the battery.
The battery voltage is calculated using following equation

$$U_B = U_0 \cdot N_{SE} \tag{11}$$

The total number of cells in the battery is calculated using following equation:

$$N = N_{SE} \cdot N_{PS} \tag{12}$$

The total power consumption of the battery is calculated using following equation:

$$C_B = N \cdot C_1 \tag{13}$$

The developed design procedure allows to achieve minimal battery mass based on required maximum battery voltage, maximum battery power and additional restrictions on the number of consecutive elements in segment.

The result of applying the developed design procedure (including the requirements listed in Table 1 and the selected battery voltage) to battery cells of Russian and foreign manufacturers is presented in Fig. 2.

	Total mass of cells in the battery, kg	Battery energy, kW*h	Total number of cells in the battery, psc
Headway 38120 (S)	139	13,44	420
Headway 38140	151	16,128	420
Headway 40160	165	16,896	330
UralElement IFP23/72/139	360	16,128	720
UralElement IFP31/133/209	324	17,28	180
UralElement IFP67/133/237	240	17,28	60
UralElement ICGP ИПЮН.563361.007 ТУ - 7.5/135/150	104	8,9856	208
UralElement ICGP ИПЮН.563361.007 ТУ - 11/215/205	70	9,828	78
UralElement ICGP ИПЮН.563361.007 ТУ - 7.5/230/355	114	18,72	104
UralElement ICGP11/215/205 ИПЮН.563361.010 ТУ	62	9,2664	78
A123 AMP20M1HD-A	42	5,92704	84
WB-LYP40AHA	144	11,52	90
Kokam SLPB 60460330H	142	21,2065	73

Fig. 2. Design procedure applying results.

According to calculation results batteries from A123 Systems [7] (outlined black in the table 2) have the most suitable parameters.

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4. Conclusions

The design procedure of choosing battery cells for the battery of electric race car, choosing their connection scheme, and calculating parameters of the battery pack was developed. Using this design procedure batteries from A123 Systems were selected to achieve the best gravimetric energy density of the battery.

References

[1] Information on http://www.fsaeonline.com/content/2016_FSAE_Rules.pdf.

[2] M. Jongerden, B. Haverkort, Which battery model to use?, IET3. (2009) 445–457.

[3] T. Huria, M. Ceraolo, J. Gazzarri, R. Jackey, High Fidelity Electrical Model with Thermal Dependence for Characterization and Simulation of High Power Lithium Battery Cells, in: Proceeding of 2012 IEEE Electric Vehicle Conference. (2012).

[4] A.A. Andreev, A.G. Vozmilov,V.A. Kalmakov, Simulation of lithium battery operation under severe temperature conditions, Procedia Engineering. 129 (2015) 201–206.

[5] R.Yu. Ilimbetov, V.A. Kalmakov, A.A. Andreev,N.P. Tychenok, Development of the experimental assembly for research of energy storage for wind turbine, Scientific Journal of CSAA. 70 (2014) 67–70.

[6] T.B. Reddy, Linden's handbook of batteries, McGraw Hill Companies, New York, 2011.

[7] Information on http http://www.a123systems.com/prismatic-cell-amp20.htm.