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# FSAE Car Electric Powertrain Analysis

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**Abstract**
The article presents technical solutions and characteristics of an electric drivetrain of a formula student car. Design experimental condition of drivetrain and the battery pack with BMS choice are discussed. The conclusions of road tests of the electric drivetrain made on roads are listed. The Electric vehicle was built in R.M.K Engineering College, Tamil Nadu.

***Keywords:*** *Electric powertrain, PMDC motor, lithium polymer battery pack, BMS*

## I. INTRODUCTION

**F**ormula Student is an engineering contest held annually in the UK. Students from around the globe design, build, test, and race a small formula mode racing car. The vehicles are evaluated on a number of parameters in Static and Dynamic events. It is organised by the Institution of Mechanical Engineers and uses the rules specified in the original Formula SAE with supplementary regulations.

Teams take on the hypothesis that they are a manufacturer developing a look alike to be evaluated for production and a group of investors are willingto invest in their project. The car must have very high performance in terms of its acceleration, braking and handling properties. The car must be cheap, easy to maintain and dependable. Also, the car‘s commercialisation is strengthened by additional factors such as aesthetics, convenience and use of common parts.

The challenge to the design group is to design and fabricate a look alike thatmeets these goals and intents. Over the period of a five day contest, a panel of experts from the motorsport, automotive and supplier industries evaluate the design, cost and business planning of all the participants to identify the best team and vehicle, in addition the team‘s on-track functioning scores will prove how well they hold up under real life conditions.

## II. TECHNOLOGICAL SOLUTION OF AN ELECTRIC DRIVETRAIN

The fictitious design concept involves creation of an electric drivetrain for a track vehicle, which would attain a top speed of 145 km/h and a driving range of 100km. Based on simple physics computations, the preliminary computations were made to estimate the required power output (P):

$$P = \frac{M.g.f_r.V_{max} + 0.5.C_x.\rho_{air}.A.V_{max}^3}{\eta_{tr}.k_p}$$

where:

*M* – mass including driver and passenger (400kg)

*g*– Earth's gravitational acceleration

$f_t$–rolling friction coefficient(0,015)

$C_x$– drag coefficient ($C_x$ =0,65)

*ρ* – air density at temperature 20°C and pressure 1013,33hPa (1,2047 kg/m3).

*A* – reference area (0,6 $m^2$).

*V* – assumed vehicle speed (145 km/h)

$\eta_{tr}$– power transmission efficiency coefficient (0,98)

$k_p$ - Compensation coefficient. of capacity (0.95)



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The calculated necessary power output was 19,84kW. Based on this figure , elements of the drivetrain were selected. The electric drivetrain consists of a Permanent Magnet DC Motor (PMDC), a Kelly controller, and a pack of 20 lithium polymer (LiPO) pouch cells. All the drivetrain components have been installed in an in-house designed FSAE Chassis as shown in the figure.1. The drivetrain uses a chain drive to transfer the power required to run the vehicle.

Fig. 1. Designed and Fabricated Chassis


Fig. 2. Saietta Agni 119R PMDC Motor

A drive sprocket was mounted directly on the motor's output shaft, which via the chain, transfers the torque to the rear wheel sprocket.

Basic PMSM motor parameters:

- Rated Power : 15kW
- Maximum Power : 25.4kW
- Rated Current 200A
- Maximum Current 400A
- Rated Torque 32Nm
- Maximum Torque65Nm
- Rated Rotation Speed3891RPM
- Size
  - Diameter : 205mm
  - H :137mm
- Cooling Type : Air

The PMDC motor's output torque is controlled by a controller. Due to small size, a large number of functions and adequate power, Kelly PMDC Controller was selected. These controllers are widely used in FSAE events. This controller can drive the motor using DC power from 12V to 72VDC. An important addition to the controller is the cooling system, which is in this case consist of a finned aluminium heat sink which operation is supplemented by a cooling fan. The controller allows the configuration of many parameters and safeguards of the powertrain, as well as parameter readout via the CAN network connection. The functions implemented in the electric powertrain include: reverse drive function , which assist the car's handling during parking, power output limiting using hidden switches, protection from use by unauthorised personnel. Thanks to the capability for configuration of the controller it is possible to freely set the limits on the torque, power and speed of the driven motor. The motor and controller are shown in the fig.2 and fig.3 respectively.

Basic Kelly KDHE controller parameters:

- rated voltage 24V
- frequency of operation 16.6kHz
- operating temperature -30℃ to 90℃
- continuous current 900A
- maximum current (60 seconds) 1800A
- cooling type: air – forced and natural


Fig. 3. Kelly KDHE Controller for PMDC Motor

The controller is powered from a battery of 20 LiPO pouch cells each of 75 Ah capacity , each weighting 2 kg. Total battery energy is 5.04kWh. The charging and discharging characteristics of the cell are shown in fig.4 and fig.5.

The important factor during operation of a plug in type vehicle is continuous tracking of the parameters of the electrical system.The battery bankposses a voltage indicator which is an LCD that shows the battery pack voltage.



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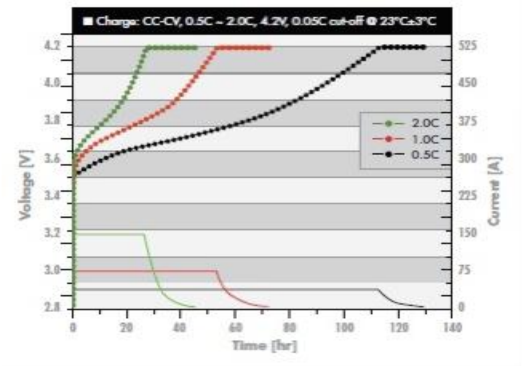


Fig. 4. Charging characteristics of LiPO cell

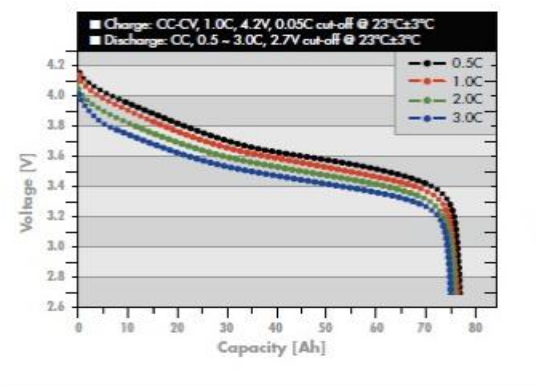


Fig. 5. Discharge characteristics of LiPO cell

**1.Charger specification**

- Input Voltage : 100-240Vac 50-60Hz
- Efficiency : Over 85%
- Working mode : Microprocessor Control
- Charging mode : Microprocessor control with Multi segment-stage CC & CV

**2.Output Protection:**

- Output short circuit protection.
- Output voltage & current limiting protection
- Reverse polarity protection and over temperature protection
- Charging time limiting protection
- Over voltage protection

**3.Temperature & Humidity :** 0-40°C & 20%-- 85%

**4.Status LED Display:**

- Waiting / Full mode : LED (Green) ON
- Charging mode: LED (Yellow) flash
- Error Charged Mode: LED (Red) flash

**5.Dimension:** 185 * 145 * 75 mm

Fig. 6. Charger

The other sub systems designed was powered by a 12V auxiliary battery. It is a 14Ah 12V Lead acid battery. Throughout testing, there were other parameters collected and stored, which include: battery bank voltage and current, the vehicle speed, temperatures of the battery,controller and the motor. During the testing, the analysis was carried out of the controller parameters governing various motor operation phases: motor start, normal motor operation, braking.

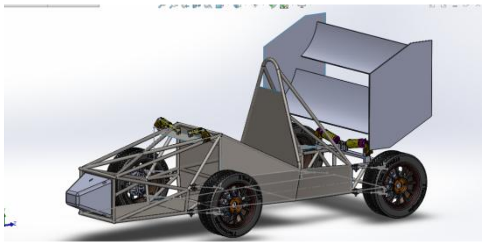

Fig. 7. CAD Design of the car

Fig. 8. Completed structure of the car

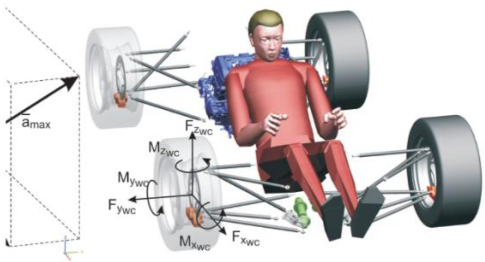


Fig. 9. Driver’s position inside the car



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## *A.* Brake System Plausibility Device

The purpose of the brake plausibility system is to ensure that the driver is not on the accelerator position pedal sensor (>5kW) and the brake pedal simultaneously. To do this, theelectric circuit takes input from the main accumulator current sensor and one of the brake pressure transducers. The circuit uses a dual comparator to compare the input signals to threshold voltages set by potentiometers. The threshold voltage for the main accumulator current sensor corresponds to when 5kW is being delivered to the motors. The verge voltage for the brake pressure corresponds to when the brake pedal is being depressed. A NOR gate will check if both inputs are above the threshold voltages and if they are, both inputs to the

NOR gate will be low (dual comparator is active low), and the NOR gate will output a 5V signal. If the signal remains for more than 0.5 seconds, the RC network will reach a voltage above the threshold voltage set by a potentiometer. The comparator will then pull the output of the BSPD circuit LOW, which The brake plausibility status signal comes from the output of the circuit above. If it is high signal (status OK) and the set/reset button is being depressed, the solid-state relay will connect the hi-Z side of

The DPST relay coil to ground and will close the contacts. The set/reset button only needs to be pushed initially or if a fault has been thrown to set/reset the circuit on. If the output signal from the brake plausibility system device is low (fault), then Z503 will open and then K500 will open. K500 will stay latched off until the status of the brake plausibility device changes and the set/reset button is pressed. The schematic of BSPD is shown in fig.10. and specification in Table.1

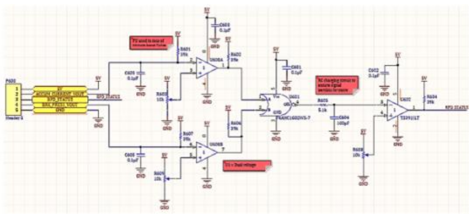

Fig. 10. Chart of example data collected during the process ofroad test of the electric vehicle

| | |
|---|---|
| Brake sensor used: | TE US300 Pressure Transducer |
| Torque encoder used: | Potentiometer |
| DC Current measurement used: | LEM sensor |
| Supply voltages: | 5V,10V |
| Maximum supply currents: | 10mA ,20mA |
| Operating temperature: | -40 to +105 °C |
| Output used to control AIRs: | Opens a relay |

## *B. Battery Management System*

BMS utilised in our design is a custom made BMS. It is designed to work in high noise environment, high EMI in harsh temperature ranging from -40C to 80C.The individual cell voltage rating ranges from 0.2V to 5V per cell tap. cell voltage resolution is about 1.5mv.It is designed for lithium polymer battery packs up-to 72V nominal voltage (84V maximum).If the voltages get near the limits it opens the AIR'S. The temperature limit is set to be 60 C and if temperature is exceeded it opens the AIR'S. All the sense wires are electrically and magnetically separated by the BMS. In the case an error is detected and the BMS needs to open the AIR'S, It switches the internal relay which connects to the internal shutdown circuit, isolation occurs between the tractive system and the low voltage system connectionswithin the BMS.

## III. RESULTS & DISCUSSION

According to the conducted research it can be concluded that the results confirm the design assumptions including the low energy consumption by the car's drivetrain. The top speed of the car was intentionally limited to 100 km/h, mostly due to rapidly increasing aerodynamic drag above 69km/h. The tests revealed that for each 10% increase in velocity increases required power by 20% to25%, increasing the speed from 49km/h to 79km/h results in almost five times moreoutput power from the motor. Speed increase from 50km/h to 110km/h resultsnearly 15 times more power required, and reaching 200km/h would need at least 30 times the power required to drive at 50km/h. The average energy consumed during driving with accordance to the eco-driving


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principles was ca.35Wh/km which reaches a range of 200km. The major factor affecting the vehicle's energy consumption is the body design, which can be characterised with the aerodynamic drag coefficient $C_x$.

The possibility of change of the controller configuration via the CAN network allows to create dedicated parameter programs which could be used for various driving scenarios, eg.: maximum range or maximum performance. The electric powertrain for an electric car, designed and built in the R.M.K Engineering College has proven its proper design and aptitude during operation on public roads.

## IV. Summary

The designed electric powertrain for a car is characterised by:

- low energy consumption of ca. 35Wh/km in relation to conventional cars (ca. 635Wh/km)
- low noise pollution, especially during start and acceleration
- high performance delivering rich experience while driving
- no emission of harmful gases and no oxygen consumption
- possibility of quick disassemble the battery pack so that you can apply them to another vehicle (car, boat).

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