The development of a novel, light weight, cost effective drive system for small electric vehicles

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Zytek Group

- A high technology engineering company formed 28 years ago to develop racing engine controllers.
- Employs 190 people on 2 UK sites, plus an office in Detroit.
- Zytek Group comprises 2 companies:-
  - Zytek Automotive. Roadcar activities, EV/HEV engineering, engine management
  - Zytek Motorsport. Motorsport activities, engine & chassis supply
- Zytek Automotive 50% shareholding by

Diversification into electric/hybrid vehicles

Technology Strategy Board
Driving Innovation

- Mid 1990s, expansion into EV/HEV market sector began, foreseeing concern over fuel supply and air quality issues
- 1st production HEV contract 1999


HV BAS


KERS


7.5T HEV


Modec/Navistar EV


Smart forfour HEV

LiFePO4


GM Silverado BAS


Chevrolet Silverado/GMC Sierra Parallel Hybrid Truck HEV


smart Hyper HEV


Small EV

Zytek smart EV (1st generation ev, 100 off)

Zytek smart EV (2nd generation ev, 1500 off)

Panoz Q9 racecar HEV

Lotus Elise EV


Chrysler ESX HEV


F3000 racecar EV


Vito taxi EV

Family car EV


LMP1 HEV



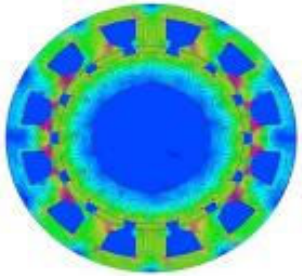
City car EV

1996 1997 1998 1999 2000 2001 2002 2003 2004 2005 2006 2007 2008 2009 2010 2011+

Key EV/HEV competences

Technology Strategy Board
Driving Innovation

- In-house design, build, test and validation of:
  - Electric motors
  - Inverters (inc DCDC)
  - Micro-processor platform
  - Embedded & PC software
- Mechanical engineering, design & prototype manufacture
- Vehicle Systems engineering, development, integration & calibration



Project Scope

- The application to the TSB (APPB2B) proposed the development of a running prototype of an ultra-efficient, lightweight, 3-seater city electric vehicle.
- The project encompassed:
  - Gordon Murray Design, lead applicant
  - Zytek Automotive, partner
  - Other sub contract organisations as necessary
- Zytek Automotive were responsible for the design and manufacture of a custom, lightweight, highly efficient drivetrain as part of a holistic approach to an optimised 3-seater city electric vehicle (EV).
  - Electric Drive Control Module (EDCM)
  - Electric Vehicle Control Module (EVCM)
  - Battery Pack & Management System (BMS)
  - Electric machine

T27 EV customer requirements analysis

- Zytek & GMD initially embarked on an intensive vehicle performance modelling task
  - Fun to drive
  - Efficiency through light weight
  - Adherence to a defined set of standards, regulations etc to ensure both vehicle safety and a path to volume production
    - SEA, ISO, IEC, FMVSS, UNECE
- Very quickly became apparent that a traditional “box in a box” approach to vehicle architecture would not be appropriate, high levels of system integration would be required to meet weight targets.
  - Component – component integration
  - Component – vehicle integration
- This approach has other benefits
  - Reduced EMC
  - Connector reliability

T27 EV customer requirements

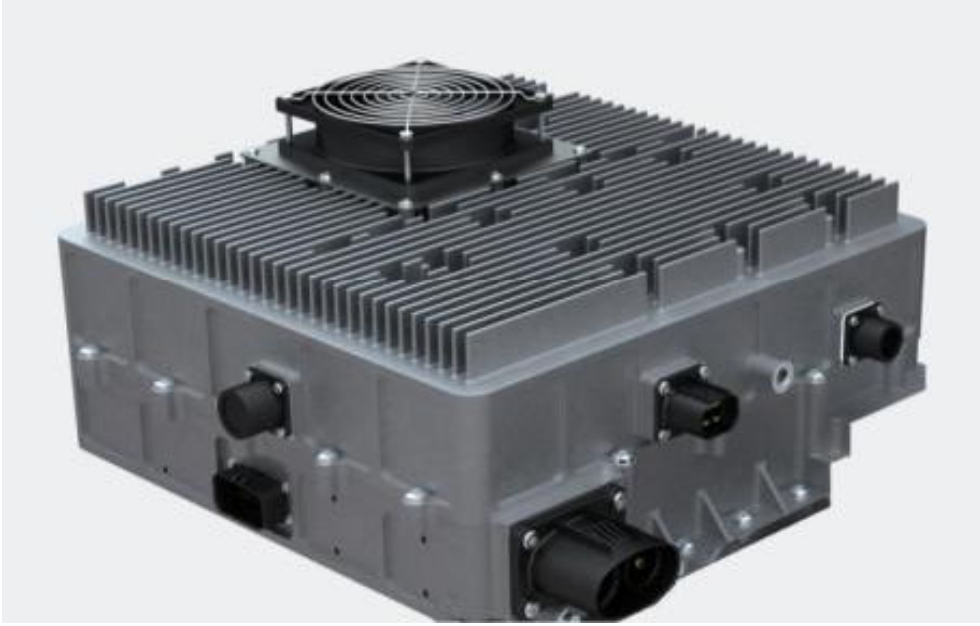
- Following extensive vehicle & powertrain simulation, the following targets were derived:
  - Peak mechanical power, 25kW for ≥ 30 seconds
  - Second peak mechanical power, 20kW for ≥ 300 seconds
  - Continuous mechanical power, 15kW
  - Peak torque @ wheels, 729Nm for ≥ 5 seconds
  - Continuous torque @ wheels, 729Nm
- Efficiency targets for motor, inverter & gearbox were also set (aggressively), to enable smallest battery to meet range targets
- Air cooling preferred, due to weight saving potential

Traction motor overview

- As customer requirements were expressed as a wheel torque, and gearbox was also designed in parallel to the motor, operating speed range could be chosen to enable low levels of motor torque whilst maintaining vehicle performance.
  - Motor architecture internal rotor, 3 phase, permanent magnet synchronous machine
  - Maximum motor speed 14,500rpm
  - Peak mechanical power, 25kW for ≥ 30 seconds
  - Continuous mechanical power, 15kW
  - Peak torque @ shaft, 64Nm for ≥30 seconds
  - Continuous torque @ shaft, 47Nm
- Gearbox reduction ratio 14:1
  - Limited by current production oil seals/bearing for automotive (non-motorsport) applications
- Weight 14kg

EDCM overview

- To minimise weight and space claim on vehicle, all major HV ancillary components were packaged in a single housing
  - 3 phase inverter 30kW ≥ 30 seconds
  - Charger 240V 3kW single phase
  - HV power distribution 2kW (cabin heater)
    - Cabin heating, air or water based systems
  - DCDC converter 675W @ 13.5V
    - Sized based on load balance work on base vehicle
- Weight 25kg



Battery overview

- Detailed vehicle based simulation activities concluded weight and capacity targets for HV battery:
  - 120kg HV battery, including case
  - 7kg HV battery cooling
  - 12kWh
    - Range 160km, NEDC capped @ 100kph
  - 30kW peak, 20kW continuous
- To ensure safety, battery should be designed to LV123 (Daimler), VW80803 (VW) & US ABC-DOE/ID10479
- Battery should be modular, to enable options for capacity & duty cycle matching
- Careful systems engineering required to fully understand trade-offs of energy & power density (gravimetric & volumetric basis), usage profiles, cell & thermal management

Battery details

- Following a wide ranging survey of current and emerging cell suppliers, Li-tec chosen as cell supplier:
  - Cells meet UN3090/UN3840
  - Intensive cell testing carried out by Glamorgan university proved quality of the cells, both in normal usage and during destructive testing
  - High levels of cell maturity (batch uniformity)
- BMS forms a key component in any automotive HV battery, functionality includes:
  - Control of cell management circuits
  - Calculation of battery charge level and charge/discharge limits
  - De-rating under environmental limits (eg over temperature)
  - Safety management & intervention (eg crash & HVIL interruption)

Battery details

- To develop a BMS to satisfy the above criteria, REAP Systems were engaged as a development partner.
- KEY BMS features include:
  - CAN internal communications (noise immunity)
  - BMS measurement of every cell voltage and alternate cell temperatures. Sensor pick-up is through bespoke interface boards.
  - The BMS includes hardware that is independent from the software for a safety shut-off path linked to each individual cell.
  - Includes a separate HVIL and crash loop that are both diagnosable for errors and/or faults.
  - Control of the advanced Gigavac high integrity contactors.
  - Diagnosed pre-charge system.
  - Dynamic voltage and current limiting via vehicle CAN bus.
  - Both CAN and PWM options for charger control system giving flexible interfacing to many popular chargers.
  - Internal thermal management drivers (heater/chiller) making it a totally self sufficient and therefore applicable for a global market.
  - High voltage isolation measurement

Powertrain weight budget

Item	Target mass kg	Achieved mass kg
Motor	20	13
Motor cooling	7	1
EDCM*	17	25
EDCM cooling	-	-
HV battery pack	120	129
HV battery pack cooling	7	3
Gearbox	15	11
Additional harness weight	10	2
Total	196	184

* Inverter, charger, DCDC converter, HV power distribution unit

Conclusions

- Zytek Automotive have designed, built and commissioned a lightweight drivetrain for the T27 electric vehicle.
- Through a clean sheet of paper design approach, and with the advantage of working in close conjunction with the vehicle design team, the drivetrain has met all targets for weight, efficiency and performance
- Vehicle efficiency, as measured over the NEDC, has met targets, and represents considerable improvement over current electric vehicles