The NEWSLETTER

Spring 2012

Contents

Title	Page
2012 R&D opportunities	1
The potential for turbo-discharging	2
Demonstrating the fuel economy benefits of exhaust energy recovery	4
Non-destructive inspection and health monitoring assessment of composite materials	6
The role and use of advanced controls in hybrid-electric vehicles applications	10
Lead carbon batteries – a new breed of lead-acid battery	13
Energy Efficient Vehicles for Road Transport	15
Suzuki Burgman fuel cell scooter	17
Racing shows the way for road car hybrids	19
World's first hybrid electric ferry fleet	21

2012 R&D opportunities

By Luke Hampton, Technology and Innovation Officer, SMMT

2012 has already been a very busy year for R&D. Some of last year's automotive specific research call deadlines are fast approaching, and several annual calls from the larger funding bodies have also been announced. To assist the industry in making the most of these opportunities, please find below a brief summary of some of the research calls that may be of interest to you and your company.

Electronics, Sensors and Photonics KTN call for UK companies interested in collaborating with Korean companies in the field of Lithium-ion batteries.
Click here for more information

EPSRC & TSB £6m call for collaborative R&D that stimulate innovation in manufacturing.
Registration deadline: 22 February 2012
Deadline: 29 February 2012
Click here for more information

FP7 Transport 2012 Move 1 €26m call for project proposals in a range of specific areas including the demonstration of urban freight electric vehicles for clean city logistics.
Deadline: 1 March 2012
Click here for more information

TSB £25m collaborative R&D and demonstration project call for the commercialisation of low carbon vehicles.
Competition opens: 20 February 2012
Registrations deadline: 21 March 2012
Deadline: 28 March 2012
Click here for more information

Make it in Great Britain Challenge to find the best new British innovations across 6 categories as part of the BIS national campaign.
Deadline: 5 April 2012
Click here for more information

TSB £2m call for feasibility studies of innovative projects across the technology sector, including the areas of electronics, photonics, electrical systems and advanced materials.
Competition opens: 12 March 2012
Registration deadline: 4 April 2012
Deadline: 11 April 2012
Click here for more information

EU Trans-European Transport Network (TEN-T) €200m annual call for projects to increase pan-European transport.
Deadline: 13 April 2012
Click here for more information

TSB £5m call for feasibility and collaborative R&D projects into sustainable manufacturing in the process industry.
Registration opens: 27 February 2012
Briefing day: 8 March 2012
Deadline: 25 April 2012
Click here for more information

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

EU Fuel Cells and Hydrogen Joint Undertaking (FCH JU) €77.5m annual call for R&D projects in Hydrogen.
Deadline: 24 May 2012
Click here for more information

Queen Elizabeth Prize for Engineering will announce the first call for nominations in February 2012.
Nominations open: February 2012
Deadline: 31 July 2012
Click here for more information

The potential for turbo-discharging

By Dr. Andy Williams & Prof. Garner, Loughborough University

The automotive industry is deeply engaged with the development of highly efficient powertrain technologies. It is widely recognised that the energy density, power density, low cost, high durability and established infrastructure of internal combustion engine powered vehicles will result in their widespread use for the foreseeable future. Internal combustion engines are likely to continue to dominate as technologies such as hybridisation and range extended electric vehicles are introduced. There is, therefore, a clear need to continue research and development into highly efficient engine technologies. Turbo-discharging is a key new technology available to the automotive industry that can offer increased torque, improved fuel economy and improved engine breathing for gas, petrol and diesel fuelled engines.

Over the last four years researchers at Loughborough University with the support of the EPSRC, TSB and Royal Academy of Engineering have successfully taken Turbo-Discharging from a fundamentally new concept idea to a working demonstrator on a 4-cylinder automotive gasoline engine. During this time the research team has developed and validated simulation tools which are now being used to quantify the fuel saving and performance potential of the system more widely across the market.

The technology

It is well known that delivering an effective engine air system is critical to the success of a vehicle's powertrain. The implementation of turbocharging increases engine power density by extracting energy from exhaust gases to pressure charge the intake system leading to reduced weight, friction losses and gas exchange pumping work. This approach delivers major reductions in fuel consumption and is a clear direction for internal combustion engine powertrains.

It is not always possible, however, to make full use of all the energy that is available to the turbine due to combustion, emissions and structural integrity limits. Turbo-compounding systems are receiving much current interest as they enable more of the energy available to a turbine to be recovered and contribute directly to crankshaft work. Turbo-discharging in combination with turbocharging is an alternative approach which uses the excess energy available to the turbine to pressure discharge the exhaust system reducing fuel consumption primarily by reducing the engine's pumping work.

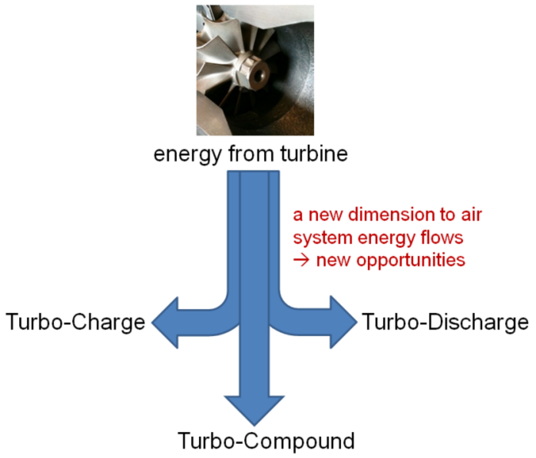


Figure 1. Diagram of turbine energy flows

Turbo-Discharging offers a new dimension to energy flows for IC engine air systems with potential fuel economy benefits, increased turbine energy recovery, reduced hot residual fraction, therefore enabling spark advance, compression ratio increase and higher levels of boost.

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

The third energy flow pathway enabled by Turbo-Discharging offers benefits that are not achievable with any other approach including:

1. The turbine outlet pressure is lower meaning that the turbine can recover significantly more energy than with a conventional turbo-charging or turbo-compounding system;
2. When in combination with an exhaust heat exchanger, a unit of turbine recovered energy can contribute to more than one unit of additional crankshaft work. Achieving this, however, is dependent on the turbo-discharger overall efficiency.
3. Significant reductions of in-cylinder hot residuals that contribute to the efficiency limiting engine knock boundary.

The full benefits of Turbo-Discharging are achieved by isolating the engine blow-down event with one of the exhaust valves opening first into a high pressure manifold and through a turbine. The recovered energy is used to depressurise the exhaust system using a downstream centrifugal compressor/pump. A low pressure manifold is connected to the cylinder through a second exhaust valve which is timed to open shortly after the blow-down event translating the low pressure into the cylinder and resulting in increased power for a given amount of fuel.

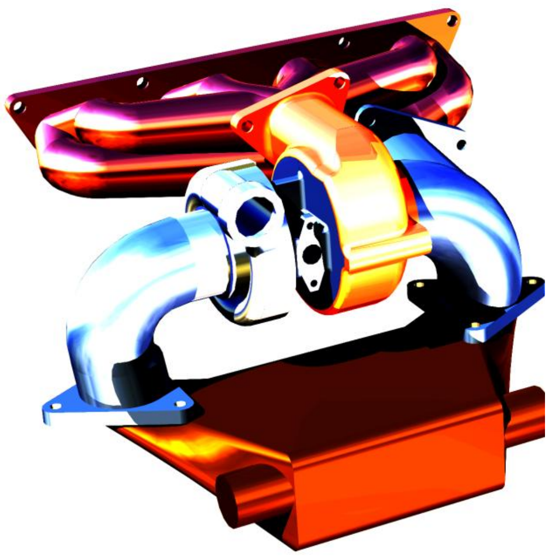


Figure 2. CAD image of high and low pressure manifolds, the Turbo-Discharger and a heat exchanger

The concept has been applied experimentally to a Ford Zetec 1.4 litre naturally aspirated gasoline engine on a test bed at Loughborough University. It delivered exhaust manifold pressures as much as 30 kPa below atmospheric pressure and torque increases of up to 7% across most of the engine speed range (see figure 3). This demonstration utilised a conventional turbocharger with an aluminium compressor wheel preventing ideal turbine/compressor rotor matching and requiring control of exhaust gas temperature entering the compressor rotor to <100°C. In addition, the retrofit-style application to an existing engine with pre-defined port and valve geometries prevented the demonstration of the full potential of Turbo-Discharging. Despite these constraints, the validity of the Turbo-Discharging concept was clearly demonstrated.

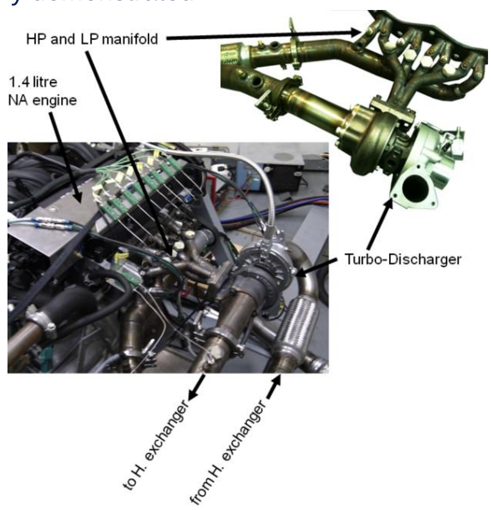


Figure 3. Demonstrator turbo-discharger unit at Loughborough University

Such results were used to validate 1-D gas dynamic engine models and allowed exploration of potential performance benefits more widely and rapidly than on-engine tests. These explorations have shown that:

1. The benefits of Turbo-Discharging are applicable to most IC engines and the technology has particular value for turbocharged gasoline automotive engines and power generation engines;
2. Steady state fuel economy benefits from pumping work alone typically range from 1% to 4%;
3. Hot in-cylinder residual fraction can be reduced by more than 50% enabling spark

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

advance or compression ratio increase to further improve fuel economy;

4. A single stage turbocharger with single stage Turbo-Discharger can offer the same engine torque curve as a two stage turbo-charging system while still realising an additional fuel economy benefit at part load.

The researchers at Loughborough University are continuing to use the unique hardware and simulation tools developed during this research to quantify the benefits in a range of applications and welcome the opportunity to undertake specific case studies with industry.

The future

Turbo-Discharging is offering improvements in fuel economy and performance across a wide range of engine platforms and across most of their operating region. In particular, the benefits are particularly valuable to turbocharged gasoline engines. As turbocharging is a key technology direction for the automotive industry, the application of Turbo-Discharging to turbocharged engines is an area that is being mapped out by the researchers at Loughborough University with the design rules and design philosophy being fully documented. The next development stage is to perform a full system level integration of the technology with a target engine including after-treatment, and then experimentally quantify the fuel economy and performance benefits before application to a demonstrator vehicle.

All the results to date support the need to investigate further the integration of turbo-discharging with modern internal combustion engines. The engine powertrain research group at Loughborough University is the largest in the country with 12 academic staff and ~35 researchers with expertise covering almost all aspects of engine powertrain technologies. The continued investment in infrastructure, hardware and support at Loughborough put them in a strong position to deliver the full potential of Turbo-Discharging in collaboration with key industrial partners and suppliers.

For more information, please contact Dr. Andy Williams at a.m.williams@lboro.ac.uk.

Demonstrating the fuel economy benefits of exhaust energy recovery

By Prof. Richard Stobart, Loughborough University

With about 30% of fuel energy being lost to the environment through the exhaust systems of modern vehicles, there is a compelling case to be made for energy recovery – to electricity – to mechanical work or to power climate control. One recovery method that has received widespread attention is thermo-electricity (TE). A TE device is a solid-state energy converter that transforms heat directly into electricity. Unlike conventional heat engines, the working fluid consists of moving electrons and a TE module consists of an array of n- and p-type semiconducting materials. Like conventional heat engines the efficiency of the device is a function of the hot and cold sources (exhaust flow and coolant respectively). In recent developments, TE devices have been exploited in radioisotope thermo-electric generators (TEGs) that power deep-space probes and in gas-fuelled generators used by the petroleum and gas industries in remote locations. Whilst such power-generation systems are extremely reliable, their relatively low efficiencies have restricted the wider application of thermo-electricity.

The efficiency of a device is determined by the materials' TE properties. High performance requires the unusual combination of a high electrical conductivity, typically found in metals, together with a low thermal conductivity, characteristics more usually associated with non-metallic systems. The optimum combination of characteristics is generally found in heavily doped semiconductors. TE materials currently in use have figure of merit (denoted ZT) values approaching unity at the temperature of operation. ZT indicates the ratio of heat flux to electrical energy flow. This corresponds to a conversion efficiency of about 5% for a temperature difference of 100K across the device. When this temperature drop is increased to 800K, the conversion efficiency can rise as high as 14%.

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

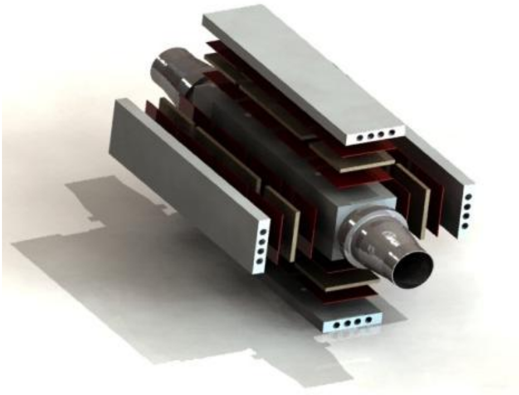


Figure 1. Picture of our first TE generator which we used for initial tests of heat exchange concepts.

Research teams from three universities: Heriot-Watt, Cardiff and Loughborough, funded by EPSRC have made a first investigation of cost effective methods of implementing TEGs for passenger cars and other applications. In a short study over the last 18 months we have confirmed the viability of new materials and how to identify the best design for a TEG. Our proposed TEG is a solid-state device that offers the promise of high reliability with a 10% decrease in fuel consumption (see figure 1). In contrast with existing approaches to heat recovery, a TE system is of much simpler and lighter construction than any competing method and can be accommodated without major vehicle design changes. There is the potential for eliminating the alternator, with corresponding reductions in vehicle weight and cost efficiency.

Our aim of recovering more than 10% thermal energy as useful work from a vehicle exhaust system requires significant advances in TE technology. However, we believe that this target is attainable through advances in module design, involving the creation of complex device structures and in the development of novel TE materials with enhanced ZT values over a wide temperature range. The majority of commercial devices are based on bismuth telluride, Bi_2Te_3 whose performance peaks at relatively modest temperatures ($ZT_{max} \approx 0.9$ at 293 K) and shows significant degradation at exhaust stream temperatures. Telluride solutions for TE devices also suffer from the rapidly increasing price of tellurium on world markets. Recently, *skutterudites* have emerged as attractive candidates for high-temperature energy recovery systems and are being widely investigated (see figure 2). Skutterudites were first found naturally in Norway, and proved to form an excellent building block for TE materials. General Motors is working with the Shanghai Institute of Ceramics to develop new generations of skutterudites, and has made significant progress. The skutterudite structure is crystalline and contains large voids. The voids can accommodate a variety of filler species yielding compounds that significantly reduce the thermal conductivity, without impairing the transport properties that lead to good thermo-electric performance.

In our project, we have placed the emphasis on a system approach, matching TE properties to exhaust conditions and understanding how the architecture of the TE system and the engine control methods can be co-optimised. TE materials have widely different efficiencies depending on temperature which leading to the need for module designs where specific formulations of TE material match the likely temperature profiles.

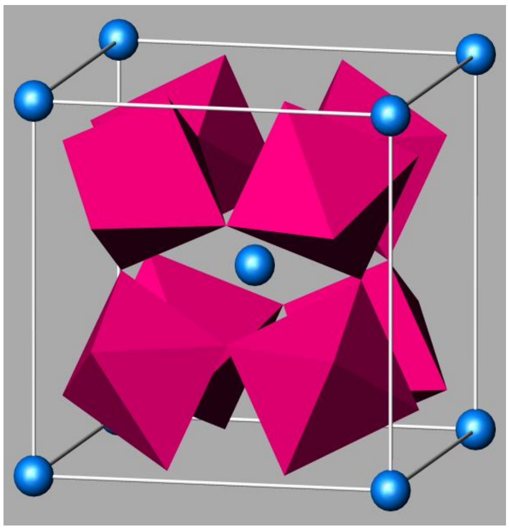


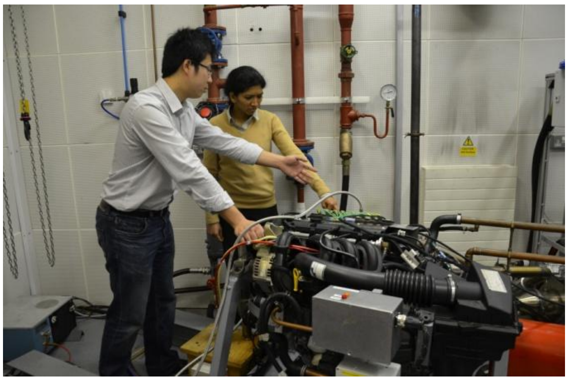
Figure 2. Skutterudite structure which provides a cost effective path to good TE performance

Where an engine is to be equipped with energy recovery there is a wide range of parameters that need to be selected to create an effective solution. Locating a device in the main exhaust path

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

potentially overcools the gas risking interference with the after-treatment system. For diesel engines a device in the EGR path represents good value. The cooling must be done, and the TE device can work in tandem with a smaller, conventional cooler to ensure that the full cooling duty is performed. In order to design a TEG, there are both heat exchange and TE parameters to be selected. Those parameters in turn depend on the required EGR flows and the resulting temperature distribution in the EGR path. In order to select the best solution, the optimisation will include a financial cost, overall fuel economy, durability and emissions. As a longer range research goal, the combination of a TEG with other functions is a desirable engineering goal. Combination of TEG with exhaust gas after-treatment is one very challenging possibility that has already been suggested by car-makers. A TEG system can also act as a heating device working as a heat pump to warm up the after-treatment system during a cold start or re-start.

Our first phase of work has revealed a number of important aspects of the technology. We identified a route to a low cost implementation of materials, and the steps needed to maintain the integrity of the TE materials. We have developed modelling and test methods that allow a rapid evaluation of heat exchange and materials properties and which support a fast optimisation requiring only a very few prototype devices. We can also predict fuel economy gains during a specified duty cycle using *component in the loop* (CIL) methods. CIL is a generic test method in which components that are in a concept or early design phase are tested on a real engine in order to assess cycle fuel economy and emissions performance. The concept or early design is created in the form of a model – possibly as CAD model or in terms of fluid flow and heat transfer behaviour. The main contribution of the CIL method is to reduce these various models to a real time computer simulation that is connected to the engine – usually through the test management system. During the test the engine behaves as if the component existed and its fuel economy, for example, reflects the integration of the component with the engine. The great value of CIL is that we can pose "what if" questions about material properties and design parameters that quickly lead to optimised designs.



The Engine Systems and Control Research Group at work

The work illustrates how a team of chemists, physicists and engineers can make a most effective contribution. The result is a clear path to a set of technologies that lend themselves to the development of a cost-effective product.

For more information, please check our project web site, www.ukteg.org.

Non-destructive inspection and health monitoring assessment of composite materials

By Joël Lévêque (Atoutveille), Matthieu Proffit (Atoutveille), Kenneth Burnham (TWI) & Simon-Peter SantoSpirito (Kingston Computer Consultancy)

Today, fuel economy has become a priority for car buyers around the globe. Automotive OEMs, under pressure from CO_2 regulations and government directives, have intensified their efforts to lighten the weight of their products for improved energy consumption and increased performance.

One way to lighten a vehicle is to include composite materials. These have been widely used for a range of applications across the surface transport sector over the last two decades and their use is expected to grow throughout the next decade.

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

The introduction of composites in automotive structural parts was originally initiated with the inclusion of glass fibre reinforced plastics (GFRP). Nowadays, the trend is to use carbon fibre reinforced plastic (CFRP) for the mass-market sector.

The recently announced BMW i3, a fully electric vehicle scheduled for launch in 2013, will be the world's first mass-produced vehicle with a passenger cell made from carbon fibre (CFRP), which will help offset the weight of the battery.

Lamborghini, an early adopter of composite materials in cars, currently manufacture the Monocoque LB834 for the Lamborghini Aventador entirely from carbon fibre reinforced plastics (CFRP). Light Resin Transfer Moulding (RTM) and co-bonding processes are used to assemble component parts, Figure 1.

Figure 1a) Monocoque LB834 assembled

Figure 1b) Monocoque RTM moulding - (Lamborghini ACRC ©)

Elsewhere, Daimler has established a joint venture with Toray Industries for the manufacture and marketing of automobile parts made of CFRP, to begin series production of CFRP components in 2012 by using short cycle resin transfer moulding.

This trend is also observed in the truck and bus industry. For example, in South-Korea, cooperation between Hankuk Fiber Co. Ltd and Hyundai Heavy Industry Co. has resulted in the development of a non-polluting electric bus featuring composite bodywork and composite interior parts. Truck trailers by Acrosoma are made entirely from composite materials, are designed specifically for heavy dynamic loads and are based on a unique and fully patented technology.

The examples so far highlighted, emphasise the need for manufacturers to adopt control and monitoring tools for the purposes of developing and maintaining composite materials suitable for various transport projects.

The ComPair project, funded by the European Seventh Framework Programme, was initiated to maximise the life-expectancy of composite components and lower overall operational and maintenance costs. Comprising eleven partners from six European countries, the three year research project investigated methods for non destructive testing (NDT) assessment and repair of composite panels in surface transport applications (cars, buses, trucks, trams and high and low speed trains).

The first results of the ComPair project

The strength of composite materials and their accompanying light weight characteristics has led to their inexorable application throughout a number of industry sectors – of which transport is just one. However, composites suffer from a high proportion of defects, which vary considerably from those documented in traditional materials used in transport (e.g. steel, aluminium), making NDT assessments incredibly valuable.

The ComPair project has developed two areas of research: *in-situ* NDT inspection and in-service

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

NDT monitoring. The inspection technique uses a scanning process that employs Transient Pulsed Thermography and Near Infra-Red (NIR) Imaging NDT techniques. These NDT techniques are selected due to their non-contact capability allowing for the potential to:

- Scan a moving vehicle
- Test pre-impregnated composite materials during manufacture
- Monitor the cure of polymer material
- Test finished products on a moving conveyor belt

NIR imaging is appropriate for GFRP materials which exhibit some transparent properties and are thus susceptible to EM radiation (NIR) of wavelength between 800nm and 1,000 nm. This method is not appropriate for CFRP materials which are opaque in NIR wavelengths and thus thermographic imaging (3-5μm and 7.5-14μm wavelengths) is best suited for the purposes of producing useful images (thermograms generated from thermal emissions emitted by the specimen surface).

The monitoring technique is provided via a combined interrogative approach using Acoustic Emission (AE) and Long Range Ultrasonic Guided waves (LRU). These two approaches are lightweight, unobtrusive and complimentary, providing a wide selection of defect indicative parameters such as threshold limits, event counting, modal and dispersion information as well as correlation related data. This combination allows for easy integration and significantly reduces the probability of false-positives.

In addition, guidelines for both the inspection and monitoring techniques have been created to produce a cost-effective manufacturing and maintenance procedure (and may contribute towards a certified test procedure).

Inspection

The ComPair inspection system is based on a robotic scanner with 4 degrees-of-freedom (DOF) that has the flexibility to accommodate two different NDT imaging techniques: Pulsed Thermography and Near Infra-Red (NIR) Vision. The developed robotic scanner, onto which the imaging NDT equipment is mounted, comprises several subsystems:

- A structural carbon steel main base
- A XYZ motion robotic system
- A rotational Smart-Head supporting the thermography equipment
- The control software

The integrated ComPair software offers full access to the developed system and guides the scanning equipment according to the inspection need. The software permits NIR inspection using a Basler camera, and transient thermographic inspection using a FLIR camera. Upon selection from the software driven menu of available test acceptance criteria, the inspection process commences with the positioning of the smart head before the surface to be tested. The inspection direction remains constantly orthogonal to the composite panel using an inclinometer and laser distance sensor integrated on the robotic scanner's head. (Figure 2).

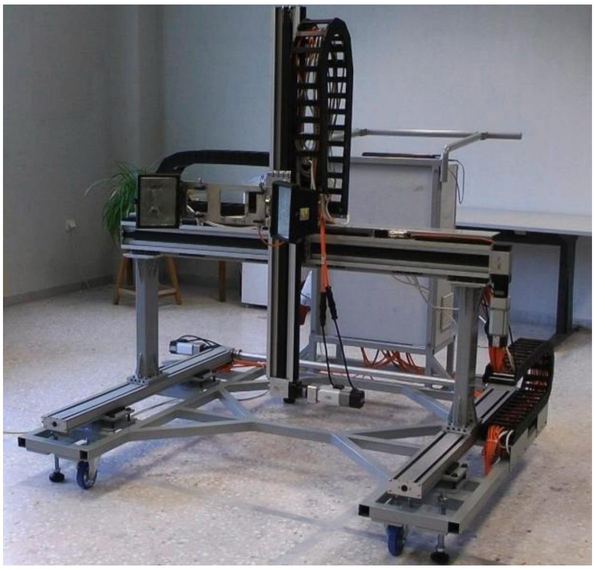


Figure 2. four axes robotic scanner (CERETETH©)

An image of the surface area being scanned is then captured before the scanner incrementally moves to an adjacent position for subsequent image capture. This process is repeated until the whole panel has been inspected. The ComPair image software stitches the images together to display on the screen a full overview of the panel

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

under inspection. The software accommodates image sizes from 100 x 120 to 1240 x 1680 pixels. The maximum array is dependent upon hardware capability but a standard premium laptop with 4GB of RAM is capable of stitching an image array of 20 x 20 images. The software is designed to be able to completely accommodate the largest composite panels used in trains and anticipate all panels used in aerospace.

In summary, the ComPair inspection system, when using NIR imaging is able to detect on GFRP:

- countersunk holes down to 12mm
- burned drilled holes down to 6mm
- impact damage (20J) down to 4.5mm diameter
- delamination down to 5mm

Using pulsed transient thermography, the system is able to detect on CFRP:

- countersunk holes down to 12mm
- burned drilled holes down to 6mm
- impact damage (60J) down to 6.5mm diameter
- delamination down to 10mm

Monitoring

The ComPair monitoring system features a dual-purpose NDT technique - based on AE and LRU - for health monitoring of full-scale composite structures during service. The integration of the two NDT techniques provides a dual-purpose sensor system able to successfully detect defects with good sensitivity. This monitoring technique offers the capability of multi-parameter defect detection and localisation due to tensile and compressive loading (figure 3).

The LRU sensors - macro-fibre composites (MFCs) - are unobtrusive, lightweight and conformable. They are particularly sensitive to in-plane damage making them appropriate for detecting fibre-damage. The AE system comprises wideband sensors (1kHz – 400kHz) and spatial pattern recognition software for localisation of defect growth. Field trials recorded by the ComPair monitoring technology showed the ability to detect growing defects over a

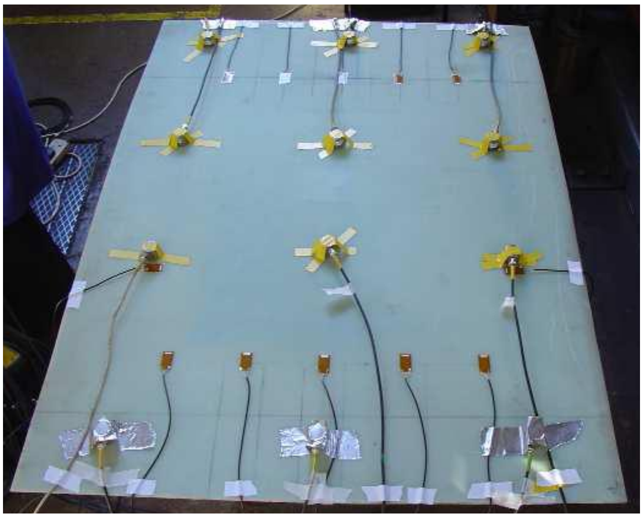


Figure 3 AE and LRU sensors placed on GFRP sample (TWI©)

distance of 1m (typical size of most surface transport panels), intrusive-damage down to a thickness of 2mm (detection of fibre-breakage) and impact damage up to a distance of 1m. Accompanying signal processing techniques (e.g. cross correlation) were able to successfully locate the area of defect growth.

ComPair project and transport sector

The examples previously highlighted, emphasise the need for manufacturers to adopt control and monitoring tools for the purposes of developing composite materials suitable for various transport projects. Since the transport sector must prioritize the safety of passengers, NDT techniques are essential.

The ComPair project provides two new and original ways of controlling composite structures. The system can run inspections during production, maintenance, assembly and service stages using a robotic scanner equipped with thermographic and NIR imaging techniques; and AE and LRU guided wave inspection for the purposes of structural health monitoring. The ComPair system provides an opportunity for automotive manufacturers to develop safer composite structures.

For a full set of article references, please contact Joël Lévêque at info@atoutveille.com

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

The role and use of advanced controls in hybrid-electric vehicles applications

By Prof. Francis Assadian and Dr. Sajjad Fekriasl
Automotive Mechatronics Centre, Cranfield University

During the last two decades, there have been substantial advances in the theory and application of robust multivariable feedback control system design. The reason for a need of such robust algorithms arises from several inherent uncertainty sources, such as various operational conditions, process changes, sensor noises and unmeasured exogenous disturbances.

While robust control systems have been successfully employed to tackle a wide range of engineering applications including aerospace systems, the automotive industry has not benefited from the advantages of these modern control techniques. However, it is interesting to note that, most of the control software designs and requirements captured in the automotive engineering domain have been adopted from the aerospace industry.

One of the main reasons for this is the fact that the process of developing automotive systems, unlike in the aerospace industry, is in a state of flux and has not been "standardised" as of yet. It turns out that there has been an increase in the gap between the control theory and the practical control strategies utilised in the existing production vehicles.

This gap has resulted in several missed opportunities through fundamental functionalities, such as fuel economy, emissions and integration of the Automotive Mechatronics units on-board the vehicle, not being addressed.

In this article, we shall briefly discuss how we have endeavoured to bridge this gap by employing robust feedback control systems design in the Automotive Mechatronics domain.

Automotive mechatronics in research

A wide range of modern automotive products are currently designed with the integration of mechanical components and electronic hardware into one packaging unit. This leads to the development of true mechatronic solutions such as HEV energy management systems, active chassis systems and next-generation HEVs etc (figure 1). On the other hand, there are various challenges for automotive systems including calibration, time and cost of production, reliability and diagnostics, control system robustness, performance issues and hardware constraints. Existing methodologies are no longer able to meet such requirements for increasingly complex new vehicles and therefore a variety of innovative mechatronics-based design methodologies are desperately required. Mechatronics applications offer one of the best solutions to the challenging requirements of the automotive industry as they offer flexible opportunities with regards to functionality, cost, space requirements and quality. The key objective of automotive mechatronics is to pursue both research and development, and a harmonised approach to the design of mechatronic systems for automotive applications.

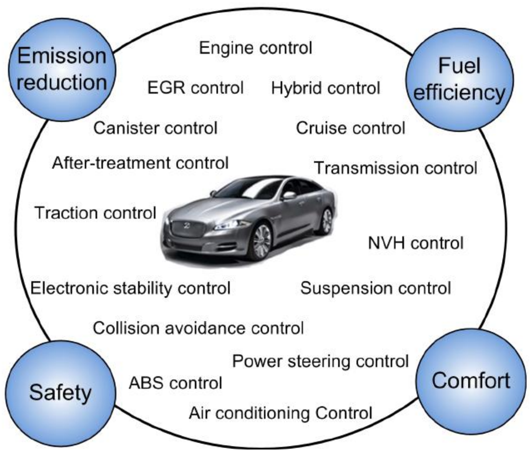


Figure 1. Automotive mechatronics applications

The technology

In our EPSRC funded research project on multivariable controls, the aim was to design and develop a pragmatic advanced model-based (dynamical) controller to the torque management of HEV which is a challenging application due to

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

the complexity of HEV dynamics. This complexity results in many challenges for both automotive OEMs and suppliers. Some of these challenges include a better definition of the roles of supplier and OEM, more efficient development processes, more expertise in the mechatronics area particularly at the OEM side, use of advanced robust control techniques and more refined integration approaches.

Our project aimed to deliver a setup with reduced fuel consumption and CO2 emissions over specific drive cycles, including the New European Driving Cycle (NEDC), by meeting the increasingly stringent emissions standards with enhanced reliability and diagnostics. This was motivated due to the fact that existing hybrid powertrain control methods are based on off-line (sub-optimal) algorithms, in which driveability is an afterthought, intrinsic model uncertainties are ignored and torque estimation errors in feedback are not considered. These are in addition to the intensive calibration efforts which are inherently required in the existing methodologies.

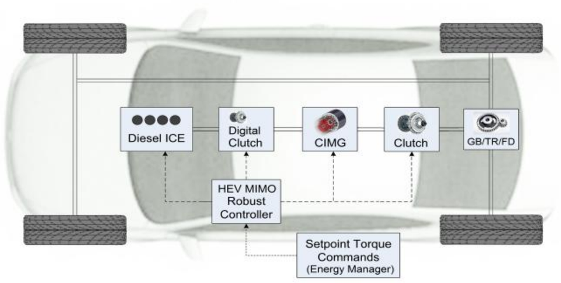


Figure 2. The structure of the HEV for the application of torque management

We have developed a Simulink package for the HEV energy management application (figure 2). This includes an empirical diesel engine model, an electric Crankshaft Integrated Motor Controller (CIMG), together with saturated actuators and torque loss models (such as ICE ancillary, pumping and friction torques). Also in the package are sufficiently realistic clutch models, adaptive torque estimation algorithms (for both ICE and CIMG output torques), an ICE speed controller and multivariable torque controllers with their associated bumpless anti-windup controls that were designed and tested in HIL (figure 3).

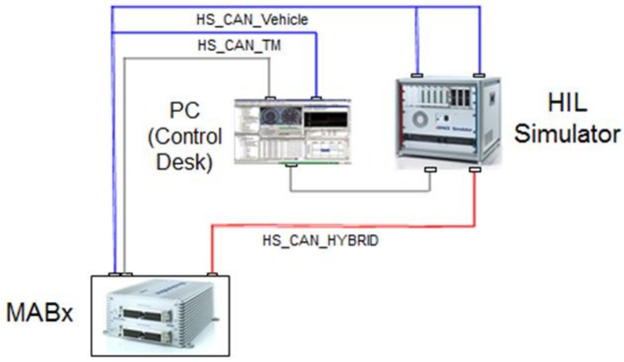


Figure 3. HIL architecture implemented based on the dSPACE platforms

The results

We intend to show some typical results of the multivariable robust control design, using mixed-mu synthesis, applied successfully to the case study of torque management of a Hybrid Electric Vehicle (HEV) (figure 4).

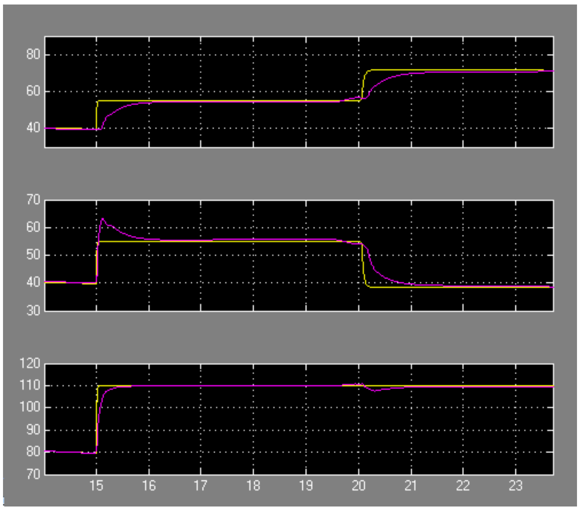


Figure 4. Robust multivariable torque control results designed and tested at Cranfield University. Yellow: Requested torque, Magenta: Estimated torque; Top: ICE torque, Middle: CIMG Torque, Bottom: Total Torque

As illustrated, the developed robust multivariable controller fully achieves our requirement from the HEV driveability viewpoint by delivering sufficiently fast total torque response. Due to different bandwidths at two ICE/CIMG control channels, the controller makes the CIMG help bring the total torque rapidly to the requested torque level. This is indeed a challenging highly-coupled multivariable control problem that single PID loops cannot cope with. Whilst the low-frequency engine output torque responses are actually delivered by the engine, at high-frequencies modes (rapid torque requests), the electric motor effectively compensates for the engine output torque lags, referred to as 'torque filling'. In other words, the HEV torque management application is a complex frequency-weighted problem which can be solved by the robust MIMO designs and as a result, drastically reduce the need for manual drivability calibration effort.

The summary

In collaboration with our industrial partners, our current research successes are in the design and development of robust controls for the challenging application of Hybrid Electric Vehicle torque management. The results of our adaptive engine brake torque estimations, aimed at both transient and steady-states, and designed for both speed-control and torque-control modes, have been very satisfactory and promising. We are now in the process of testing these torque estimations and are planning to write an invention disclosure in due course.

It has been our intention to highlight that the missed opportunities within automotive applications could have been addressed by utilising advanced control techniques. It is our hope that the results of this research work could motivate the automotive industry to pay sufficient attention to advanced and robust control designs and their potential capabilities in addressing a broad range of complex applications. Effective automotive control systems can improve vehicle performance and driveability whilst continuing to reduce costs and reach new emission standards.

Cranfield Automotive Mechatronics Centre

Cranfield University is one of the leading institutes of higher education in the UK in the fields of design and engineering of automotive technology. To meet the challenges of pioneering automotive research, The Automotive Mechatronics Centre at Cranfield University was established in 2009 to help address some of the applied advanced control issues discussed above.

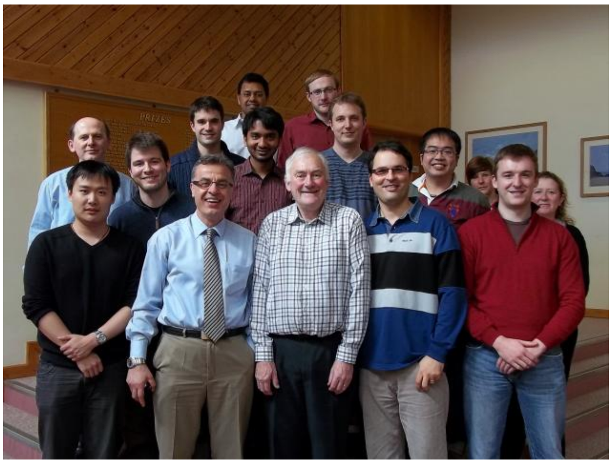


Figure 5. The Automotive Mechatronics Centre, Cranfield University.

Our research activities are mainly focused on vehicle electrification (novel electrical and control architectures), advanced automotive control and energy management strategies, vehicle Dynamics and integrated chassis Control. The overarching goals of this centre are listed as follows:

1) To address the immediate needs and gaps in mechatronics and advanced control system design and knowledge in a coordinated pragmatic approach through short term projects with industry.
2) To carry out long term fundamental research in the automotive green technology area, from process and methodology, to mechatronics modelling, design and development, through governmental support and long term industrial projects.
3) To address the knowledge gap in automotive mechatronics through short courses as well as establishment of an MSc program in Automotive Mechatronics in 2013.

For further information, please contact Prof. Francis Assadian, Director of the Automotive Mechatronics Centre, Cranfield University on +44 (0) 1234 754 657, or at f.assadian@cranfield.ac.uk.

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

The NEWSLETTER

SMMT INNOVATION AND TECHNOLOGY

Spring 2012

Lead carbon batteries – a new breed of lead-acid battery

By Dr. David Stone, University of Sheffield & Allan Cooper, EALABC

Lead-acid (PbA) batteries are today's most mature rechargeable battery technology, with over 150 years of development behind them. In hybrid electric vehicle (HEV) applications their cycle life is typically short at around 500 to 1000 cycles, as they suffer from sulphation when used in a partial state of charge (PSoC), prompting the chemistry to be dismissed in favour of the more expensive NiMH and Li-ion cell chemistries for these applications.

Recent work carried out in this field has lead to much improved PSoC cycle life with the inclusion of carbon in the battery negative plate, leading to reduced sulphation of the plates. Furthermore, the direct combination of PbA batteries and supercapacitors at cell level leads to the natural sharing of the current between the battery and supercapacitor during operation, as may be seen in figure 1.

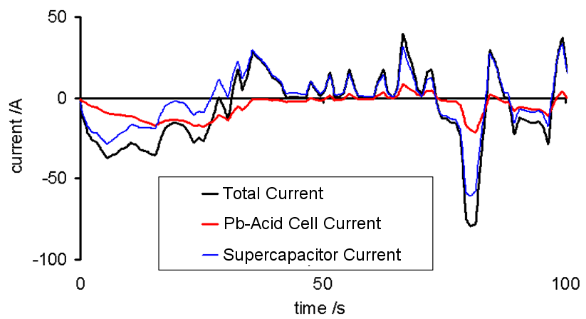


Figure 1. Ultracapacitor in parallel with a PbA cell

Here the total current drawn from the cell and supercapacitor comprises a transient component from the supercapacitor, and a PbA cell current which contains significantly fewer high frequency pulses than would be seen if the current was supplied directly from the PbA battery alone, leading to longer cell lifetimes.

This natural sharing of the current without the extra expense of a power electronic converter, has lead to the development of a single solution combination of a PbA battery and a Lead-Carbon ultracapacitor within the same package. This is to lower the peak currents seen by the traditional battery cell plates, and hence increase the battery lifetime, in addition to increasing the peak power capability of the overall 'battery', an example of which is shown in figure 2.

Figure 2. Furukawa UltraBattery prototype

Traditionally, the equivalent circuit of a PbA battery can be approximated by the 'Randles' equivalent circuit, figure 3a, with the batteries 'energy storage capability' appearing as the bulk capacitance (C_{Bulk}) together with the surface transfer capacitance ($C_{Surface}$), and the internal resistances (R_i, R_t & R_d)

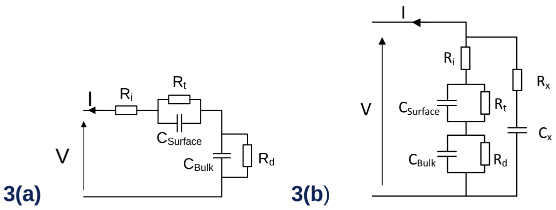


Figure 3 . 'Randles' PbA model, and modified Ultra-Battery model

Work carried out at the University of Sheffield on characterising and understanding the new technology has identified, from experimental tests and modelling of the device, an additional capacitance, (C_x), in parallel with the traditional battery elements, shown in figure 3b, which may be clearly seen in the impedance frequency response of a new battery, shown in figure 4.

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

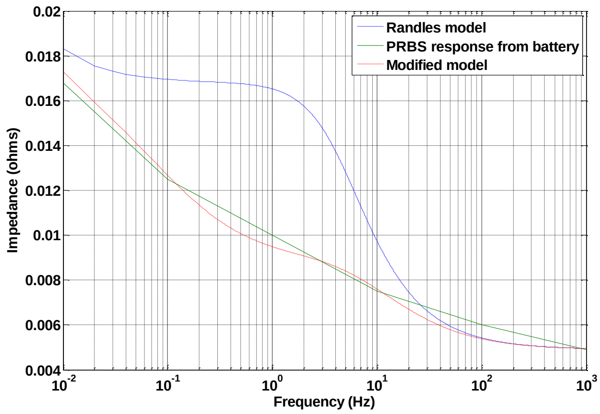


Figure 4. Ultra-Battery impedance response

The experimental results clearly show an extra parallel capacitance in the equivalent circuit with a capacitance of around 100F in series with 6mΩ, in parallel with the traditional battery components, as shown in figure 3b.

This extra 'in-built' capacitance is able to support high current pulses with a lower terminal voltage drop than is seen with a standard comparable battery under the same conditions, which could lead to a cheaper alternative battery for the ranges of HEVs under development. With this in mind a pack of twelve 12V 7.0 Ah UltraBatteries was retro-fitted to a Honda Insight by the European Lead Acid Battery Consortium (EALABC), to replace the NiMH battery in the car. This was then run on a demanding cycle at Millbrook Proving Ground for 100,000 miles without any battery problems (figure 5).

Figure 5. Insight under test at Millbrook

This has shown that advanced carbon-containing lead-acid batteries can handle the hybrid duty cycle and some of the outcomes of this development have been recently fed into the TSB funded project 'HyBoost' project, by the EALABC who are also collaborators on an EPSRC funded research work at the University of Sheffield, on modelling the advanced UltraBattery and predicting the State of Charge (SoC) and State of Health (SoH) of EV / HEV batteries. This aims to show that a drastically down-sized 1.0 litre engine in a Ford Focus can deliver near 2.0 litre performance by power enhancement through turbo charging and electric supercharging (to eliminate turbo lag) but with much lower CO_2 emissions. The energy recovery system on this vehicle is lead-acid with supercapacitors as described earlier.

Figure 6. The EALABC LC Super Hybrid

The EALABC work has shown that an advanced carbon-containing lead-acid battery can perform this duty cycle at lower cost but with a much increased energy capacity. Subsequently a 1.4 litre VW Passat has been similarly retro-fitted to enhance performance and is running with these advanced lead-acid batteries without supercapacitor support (the LC Super Hybrid – figure 6).

Overall the project is helping to understand the effects of high levels of carbon in the PbA chemistry, which in turn will lead to cheaper battery availability for HEVs and better fuel efficiency for the consumers, leading to lower vehicle emissions overall.

Energy efficient vehicles for road transport

By Bob Simpkin, Senior Engineer, MIRA Ltd

Road transport alone contributes about one-fifth of the EU's total emissions of carbon dioxide (CO_2), the main greenhouse gas. With this in mind the Energy Efficient VEhicles for Road Transport (EE-VERT) project is working towards a 10-12% reduction in fuel consumption and CO_2 generation for conventional vehicles by implementing only minimal changes to existing vehicle platforms.

Hybrid Electric Vehicles (HEVs) and Full Electric Vehicles (EVs) currently offer good CO_2 savings, however their market penetration is slow, meaning conventional vehicles are likely to play a significant role for the foreseeable future.

Despite improvements in modern conventional vehicles, a considerable amount of energy is wasted due to the lack of an overall on-board energy management strategy. One way to alleviate this is to electrify auxiliary systems and operate them only when needed which will generate energy and efficiency gains. However, there is an additional need for a coordinated approach towards the generation, distribution and use of the energy.

By bridging the gap in the market between current conventional vehicles and HEVs/EVs, EE-VERT offers an innovative solution to this problem (see figure 1).

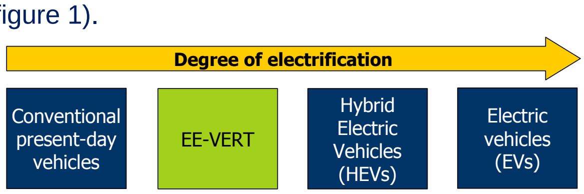


Figure 1: Market gap between present conventional vehicles and HEVs/EVs

Central to the EE-VERT concept is the electrification of auxiliary systems and the supply of their energy (from energy sources such as recuperated braking energy, waste heat recovery or solar cells) and forming an overall energy management strategy. With a conventional car using a 14V network, the EE-VERT concept is able to retain the majority of the existing components to minimise additional costs. Furthermore, improved efficiency and power is achieved by the generator operating at 40V.

To enable the elements of the standard electrical system to be connected, a new architecture has been devised that works with 40V and 14V levels (figure 2).

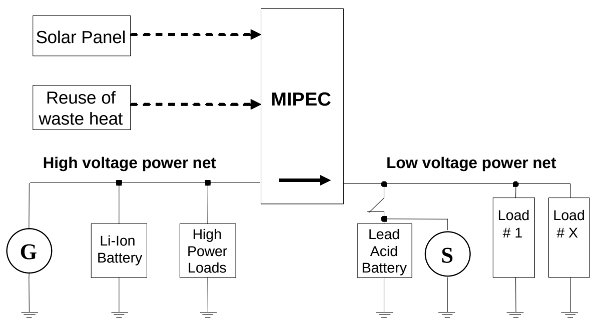


Figure 2: The EE-VERT power net architecture

The main components of the 40V network consist of a new generator based upon claw pole technology with integrated permanent magnets, a Li-Ion battery system and a DC/DC converter with multiple inputs (MIPEC) for interfacing between the two separate voltage levels and an additional energy source e.g. a solar panel. By combining the network's components in such a way, up to 10kW of generator power can be made available during recuperation, with the new generator's efficiency increasing to 70% or greater depending on the speed.

By selecting Li-Ion for the battery, MIRA was able to satisfy the key requirements of accepting a 10 second, 10kW charge pulse during recuperation. The main characteristics of the MIRA battery are shown in Table 1.

Cell Characteristic	Values
Cell capacity and chemistry	8Ah, $LiFePO_4$
Configuration	12 series and 8 parallel
Battery capacity	64Ah
Nominal voltage	40V
Maximum charging voltage	44V
Maximum charging current	250A

Table 1: Characteristics of the Battery

Drawing from previous experience in the design and construction of battery packs for innovative projects such as Limo-Green, MIRA was able to supply a unit complete with a battery management system and communications using the automotive standard CAN message-based protocol.

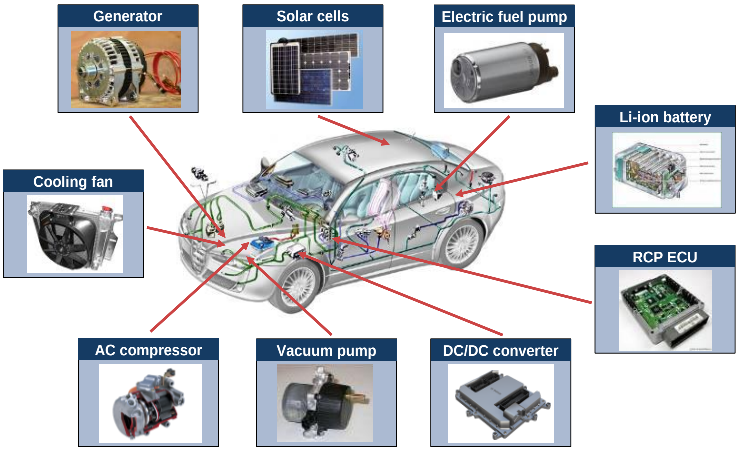


Figure 3: EE-VERT components for the demonstrator vehicle

Although the potential savings for the components are shown in table 2, the actual savings experienced will be dependent upon the driving conditions, the energy management strategy applied and the behaviour of the driver. However, initial indications suggest that the amount of energy saved should exceed 10%.

EE-VERT Measures	Comments	Benefit range on NEDC		Benefit range on mission profile	
Power Generation		Pessimistic	Optimistic	Pessimistic	Optimistic
Energy recuperation during braking(generator, Li-ion battery, DC/DC)	Recovered energy can supply the basic powernet load of 350W	4.2%	4.2%	4.2%	4.2%
Use of solar energy (Solar panel)	An average power of 100W can be supplied on a sunny day.	0.0%	0.0%	1.2%	1.2%
Electrified Auxiliaries					
Electric engine oil pump	Operation on demand possible. Engine pre-lubrication for start-stop to reduce drag starting ICE.	1.0%	2.0%	0.5%	1.0%
Electric water pump	Optimised thermal management of engine can improve engine efficiency by up to 2%.	0.5%	1.0%	0.5%	1.0%
Engine cooling fan		0.0%	0.0%	1.0%	2.0%
Electric fuel pump	Operation matched to specific demand rather than maximum.	1.0%	2.0%	1.0%	2.0%
Electric power steering	Operation on demand. No hydraulic fluid.	2.0%	4.0%	1.0%	2.0%
Electric vacuum pump	Only operates when required.	1.0%	2.0%	1.0%	2.0%
Electrical actuator for the Variable Geometry Turbocharger	An enabler for vehicles without a vacuum system.	-	-	-	-
Lights (LED)	LED lights have a longer life than conventional lamps.	0.0%	0.0%	0.0%	0.5%
AC compressor, electrically actuated	Operation possible during stop phase.	0.0%	0.0%	2.0%	4.0%
EE-VERT Concept		9.7%	15.2%	12.4%	19.9%

Table 2: Initial assessment of fuel consumption savings

Considerable simulation work has been undertaken since the start of the project. Figure 4a and 4b shows comparative fuel consumption results for various drive cycles (H2W; home to work, W2H; work to home, SAT; Saturday leisure, SUN; Sunday leisure, Freetime and NEDC; New European Drive Cycle).

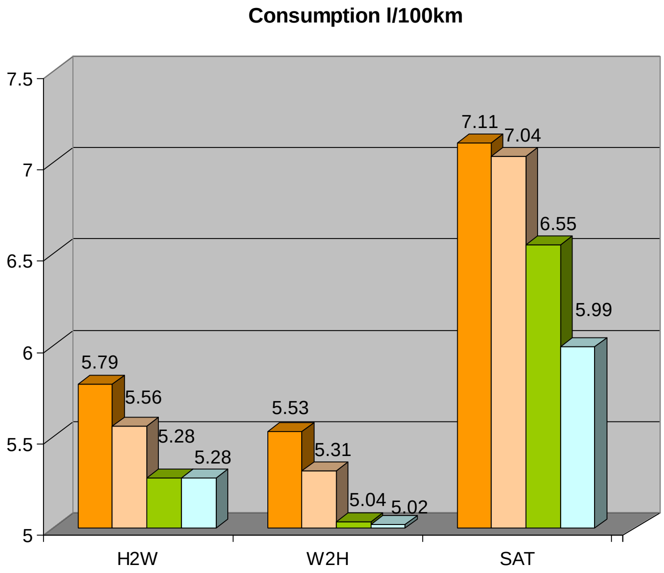


Figure 4a. Comparison of fuel consumption over the home to work, work to home and Saturday

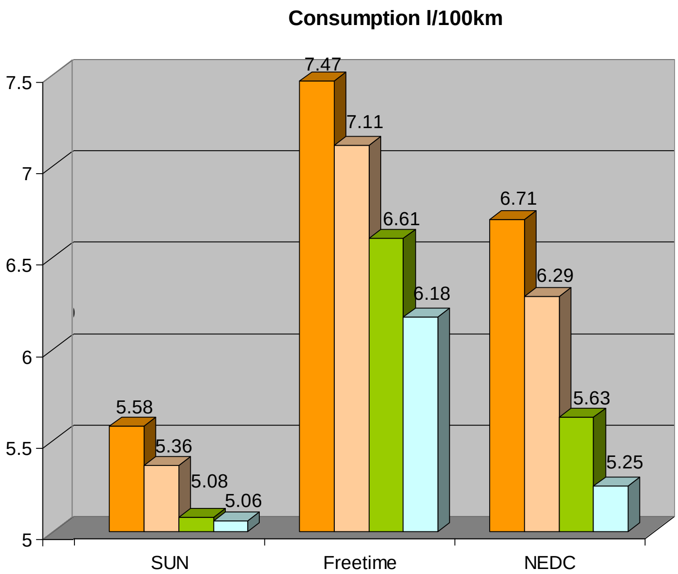


Figure 4b. Comparison of fuel consumption over the Sunday, Freetime and New European Drive cycles

The orange bar represents the original or Reference car with the normal architecture and low voltage power generation and mechanical components. The pink bar establishes the new architecture "EE-VERT Car" for the power generation and the high voltage powernet, but with original components. The green bar shows that the "EE-VERT Car" decreased its fuel consumption with the usage of new components. Further improvement can be observed at the pale blue bar where stop-start (SAS) functionality was applied.

Consider the situation for the "Freetime" drive cycle (figure 4b). Fuel consumption of the standard or reference car is 7.47 l/100km in comparison to Fuel consumption of the EE-VERT car with SAS which fell to 6.18 l/100km; a reduction of over 17%.

Organisation	Principal Roles
MIRA Limited (UK)	Coordinator, Li ion battery, AC compressor testing, Driver behaviour, Impact on safety systems.
Volvo Technology AB (Sweden)	System work package leader, Quality plan, Impact on commercial vehicles, Life Cycle analysis
Centro Ricerche Fiat (Italy)	Requirements, Demonstrator car
Robert Bosch GmbH (Germany)	Components leader, Generator, Vacuum pump
LEAR Corporation (Spain)	Multi-input DC/DC convertor, System test bench
Engineering Center Steyr (Austria)	Novel actuator for VTG turbocharger
FH-Joanneum (Austria)	Simulation software, Solar panels
Universitatea Politehnica din Timisoara and SC Beespeed Automatizari, (Both Romania)	New generator and actuator technologies

Table 3. The EE-VERT Consortium

Simulation work carried out by the partners indicated that average fuel savings of around 8-9% for real life driving cycles could be found, rising to 17% when the start and stop functionality is applied. On the NEDC the use of the EE-VERT components suggested a 16% saving. The final phase of the project, testing the demonstrator car, will confirm the potential fuel saving benefits of the EE-VERT concept.

EE-VERT is a collaborative project: with MIRA taking the role of project coordinator. Split into work packages, each section has a team a leader. The members of the consortium, with their principal roles, are shown in Table 3.

The EE-VERT project is supported by the European Commission's Seventh Framework programme, grant reference SCS7-GA-2008-218598.

For more information please contact Bob Simpkin of MIRA on +44 (0)24 7635 5460 or at bob.simpkin@mira.co.uk

Suzuki Burgman fuel cell scooter

By Dr. Jon Moore, Director of Communications at Intelligent Energy

There is clear need for a cleaner, practical alternative to the internal combustion engine, which currently powers over 800 million vehicles around the globe and accounts for 19% of global carbon emissions. UK-based clean power systems company, Intelligent Energy, along with many automotive manufacturers believe that hydrogen fuel cell vehicles are vital to the decarbonisation of transport.

Hydrogen fuel cells produce electrical energy by combining hydrogen and oxygen together in an environmentally benign electrochemical reaction, producing only heat and water as by-products. A fuel cell can be more than twice as efficient as the internal combustion engine, which must burn fuel to create heat, converting that heat into mechanical energy and then electrical energy. All these conversions cause energy losses, reducing the engine's overall efficiency. Environmentally, hydrogen is the optimal energy carrier for fuel cells, because fuel cells that run on hydrogen generate zero carbon emissions.

Intelligent Energy has designed its fuel cell systems from inception for motive power applications, with mass manufacturability, high efficiency and reliability in mind. Proton Exchange Membrane (PEM) fuel cells are used as they display the highest power densities of any fuel cell type, making them particularly suited to transportation and portable applications where the minimum size and weight are required. PEM fuel cells are free from corrosive liquid electrolytes and operate at low temperatures (below 100^{o}C) which enable in-expensive fabrication methods and materials to be used.

Figure 1. The Suzuki Burgman fuel cell scooter

In the company's proprietary air-cooled fuel cells, the cathode plates are open to ambient air, with a low power fan providing the dual function of stack cooling and oxygen supply. This results in a simple fuel cell system with low parasitic losses (the electrical power drain due to fuel cell support systems). The fuel cell system is designed for rapid, automatic load following, meaning the operating power is directly linked to vehicle requirements.

In 2005, the company designed and built the Emissions Neutral Vehicle (ENV), the first purpose built hydrogen fuel cell motorbike in the world. The following year, Intelligent Energy began development work with the Suzuki Motor Corporation, resulting in the two companies sharing expertise in order to design, test and manufacture a zero emission hydrogen and electric hybrid scooter suitable for mass production: the Suzuki Burgman Fuel Cell Scooter.

Powered by Intelligent Energy's advanced air-cooled fuel cell power system, which reacts to individual driving styles, optimising for increased range and performance, the Burgman Fuel Cell Scooter has a practical driving range of 220 miles (350km) and is easily refuelled in five minutes. The vehicle also meets the highest EC safety regulations, complying with European Standards for Fuel Cell technology (BS EN62282-2:2004).

An innovative power-train was needed to provide the scooter with a comparable range (~200 miles) to the petrol model. A purely battery powered scooter would be incapable of delivering this range, while a purely fuel cell based scooter would require a large fuel cell adding weight, volume and cost to the vehicle. The solution determined by the engineers was a hybrid power train, combining the enhanced energy density of a fuel cell system with the rapid power flow of batteries to satisfy both power and extended range requirements. In addition, the on-board hydrogen tank can be refilled in a time akin to the conventional petrol model.

The Burgman Fuel Cell Scooter features a fully integrated fuel cell electric hybrid system with

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

regenerative braking, enabling the electric motor to transform kinetic energy from the rear wheel into electrical energy stored in the battery. The fuel cell system recharges the battery and provides energy for propulsion when cruising, with the battery used to provide additional power instantaneously for acceleration. Over shorter distances, where most commuter vehicles exhibit poor fuel economy and high tailpipe emissions, the Burgman Fuel Cell Scooter produces zero emissions and yet matches the driving range of conventional petrol scooters.

Utilising the frame of the petrol-powered Burgman scooter, already mass produced by Suzuki and globally certified for public use will enable faster commercial deployment of the Burgman Fuel Cell Scooter. Many innovations have been required to integrate the entire fuel cell system, hybrid electric power-train, hydrogen storage tank and other components into the limited space available. Economical fabrication materials and a design that reduces system size and keeps component count to a minimum have produced a light weight and compact fuel cell system suitable for low-cost, high volume manufacturing.

Dr Henri Winand, Chief Executive, Intelligent Energy (left), with Mr Osamu Suzuki, Chairman, Suzuki Motor Corporation (right) and the Suzuki Burgman Fuel Cell Scooter

Since early 2010, a fleet of Burgman Fuel Cell Scooters have participated in a public road testing program run by Intelligent Energy, with funding and support from the UK Government's Technology Strategy Board. Initially conducted at sites in the East Midlands, the program will soon be extended to London, and other large cities, where zero emission vehicles have the greatest potential to reduce carbon emissions and improve urban air quality.

Suzuki has publicly stated that its aim "is to make eco-friendly fuel cell scooters increasingly common in Europe." To that end, Intelligent Energy and Suzuki have obtained Whole Vehicle Type Approval (WVTA) for the Burgman Fuel Cell Scooter – the first time any fuel cell vehicle had achieved this level of certification. WVTA, a specified EU performance standard, qualifies the scooter as safe to use on public roads without having to be inspected and tested individually, and also approves the design for production across Europe.

For more information, please contact Dr. Jon Moore, Director of Communications at Intelligent Energy on 01509 271271. Alternatively, please visit http://www.intelligent-energy.com/

Racing shows the way for road car hybrids

By Jon Hilton, Managing Partner, Flybrid Systems LLP

SMMT Award for Automotive Innovation finalist Flybrid Systems is using motor racing to showcase the latest in hybrid car technology. In June 2011 the first ever hybrid car raced at the famous Le Mans 24 hour race but unusually it was not entered by a top factory team like Audi or Peugeot and it wasn't electric. Instead it was a privateer car using an entirely new type of mechanical hybrid system based on high speed flywheel technology.

The hybrid system used on the Hope Racing car was developed by Flybrid Systems in the UK and is the first to feature Flybrid's patented Clutched Flywheel Transmission (CFT) that uses a series of small, high-speed rotating, clutches to transmit the drive between car and flywheel. Storage comes in the form of a small 5kg flywheel made of steel and carbon fibre that rotates at up to 60,000 rpm.

THE SOCIETY OF MANUFACTURERS AND TRADERS LIMITED
SMMT, 71 GREAT PETER STREET, LONDON SW1P 2BN
T +44 (0)20 7235 7000

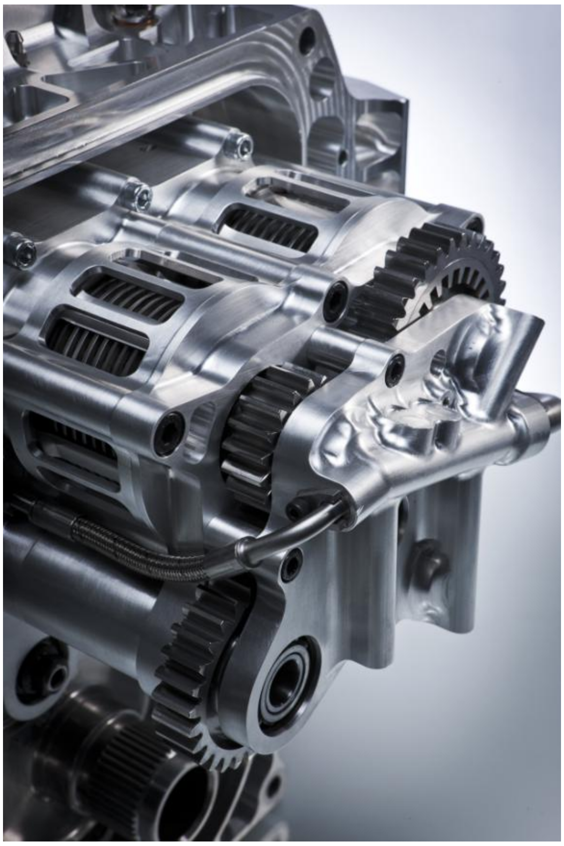
The small clutches of the CFT are of the normally open wet multi-plate type and are closed by hydraulic pressure. The entire electronic control and hydraulic systems have also been developed by Flybrid who write the control software in house as well as make their own hydraulic pumps, actuators and valve blocks.

The Hope Racing LMP1 car was the first ever hybrid car to race at Le Mans

Being a racing project the development of the system was completed with no prototypes. The Hope Racing team bought two complete systems plus a pre defined package of spares and these parts were made in a single batch on the assumption that all would work just as described by the Matlab Simulink simulation and the design calculations. Some updates were required after the early system tests but more than 95% of the components worked exactly as predicted first time. This is normal for racing product development and in fact the time scale allowed for the project meant it had to be the case. The client placed a purchase order for the work on the 11th October 2010 and the car ran for the first time on the 21st April 2011. Considering that everything was completely new including even the concept of the transmission this was a fantastic achievement.

This pace of development comes at a price and the system components were very expensive given the short time allowed for manufacture. The 13 gears in each system for example needed to be manufactured from steel bars in just 5 weeks. No supplier was able to achieve this timing so Flybrid turned the gear blanks in house, had the gear profile spark eroded with the stock on, heat treated the steel to full hardness, hard turned the parts in house to the finished size and then found a supplier that could do just the last gear grinding operation.

The system is designed to cope with the rigors of Le Mans where the 900 kg, 325 km/h car will cover over 5,000 km in a day. With seven big storage (braking) events per lap the energy store will be cycled over 2,500 times during the race distance and experiences no performance degradation at all which is a key characteristic of flywheel based hybrid systems.



The new clutch based transmission provides 135 kW in a small package space

The performance statistics of the system are very impressive as it is rated at 135kW power and 540 kJ storage capacity yet weighs less than 38 kg for the complete system including all the associated pumps, wiring loom and fluids. During the race at Le Mans the internal fluid temperatures remained stable at 92^{0}C verifying the very low heat rejection to the oil cooler of just 5 kW.

The system is engineered as an integral part of the car and the gearbox closing plate that the system is built into even carries rear suspension loads. This means that the system needs to be robust to significant vibration, shock loads and temperature.

The Flybrid system is fully integrated into the rear of the car fitting between engine and gearbox

A lot of development effort has gone into the control aspects of the system as it needs to operate fully automatically with no driver input and must react very quickly to gear shift requests from the paddle shift system as well as inputs from the driver throttle and brake pedals. The control system includes an engine-off driving mode that is required by the series regulations. The car is capable of driving about 1/3 mile on the flywheel alone with the engine turned off.

Flybrid have already secured several road car programmes that use this CFT technology and have several others in discussion. The unique properties of high power, low weight and long life at full performance have clearly won over Hope Racing but it is the very low cost potential that excites road car clients. Flybrid expect the cost in mass production of this type of system to be around 1/3 the cost of an equivalent electric hybrid system.

For more information, please contact Jon Hilton, Managing Partner, Flybrid Systems LLP on +44 1327 855190. Alternatively, please visit www.flybridsystems.com.

World's first hybrid electric ferry fleet

By Luke Hampton, Technology & Innovation Officer, SMMT

The Hong Kong Jockey Club recently launched four sea ferries to transport golfers around their island based golf course. The vessels make up the world's first hybrid electric ferry fleet. Australian company Solar Sailor developed the ferries with a diesel-electric parallel hybrid powertrain, a system very similar to that used in many hybrid-electric vehicles.

The solar panels charge the vessel's batteries, which in turn power the propulsion system alongside a diesel engine to reduce the emissions of each journey by a reported 8-17%. This system also allows the vessels to enter and exit harbours on battery power alone. One vessel even manages to raise its panels for use as sails for additional power.

Solar Sailor plans to extend the solar sail concept to larger freight vessels. Their estimates suggest fuel savings from the sail power could be between 20-40%, with the solar panel adding a further 3-6% saving.

Solar Sailor's solar powered hybrid electric ferry

With technology developments gathering pace in the automotive industry, it will be interesting to see, which technologies will cross over between modes within the transport sector over the coming years. For more information, please visit: http://www.solarsailor.com/