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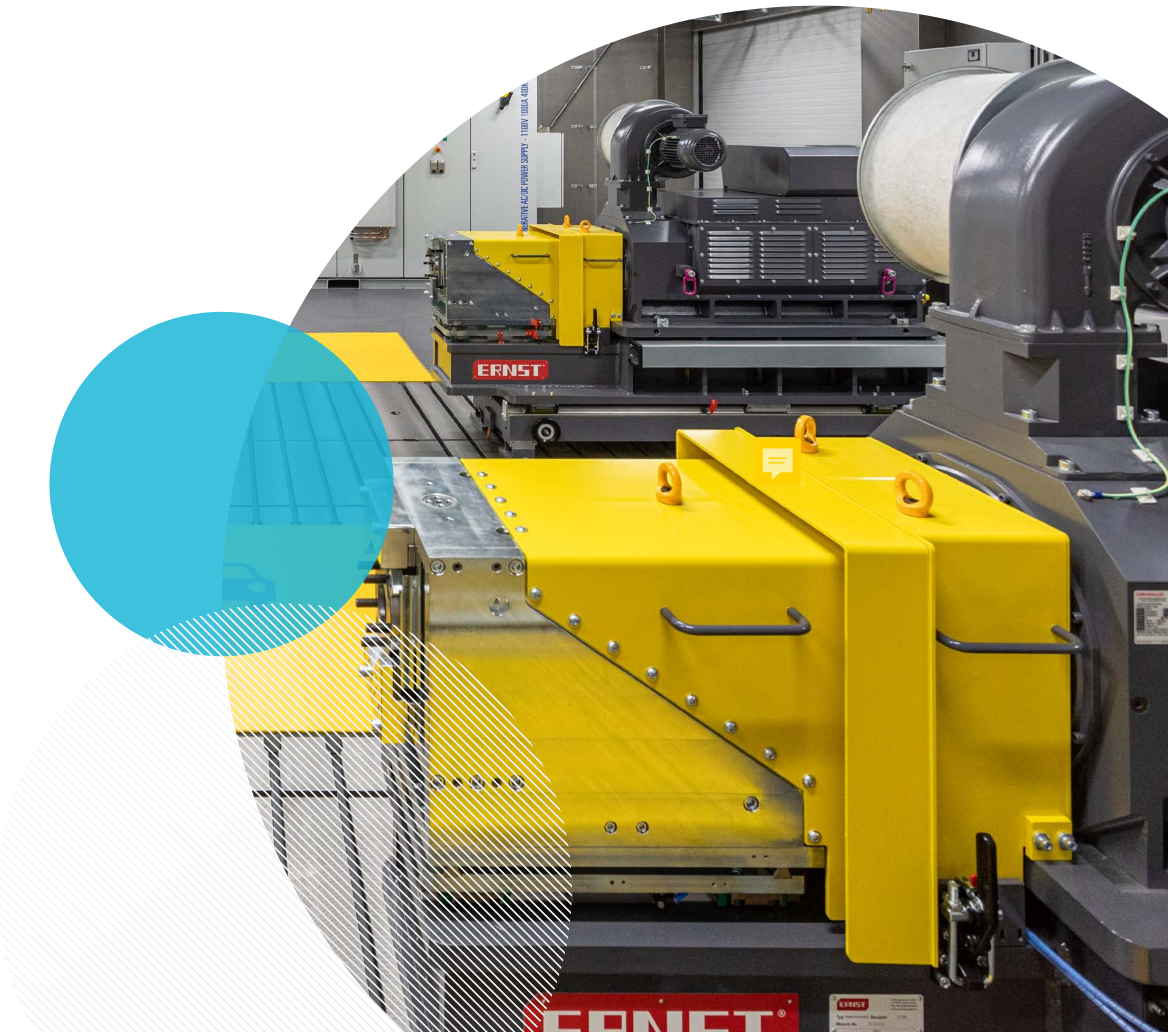
WHITE PAPER

DEVELOPMENT TESTING OF POWERTRAIN TECHNOLOGIES FOR FORMULA E

AND OTHER ELECTRIC MOTORSPORT SERIES



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INTRODUCTION

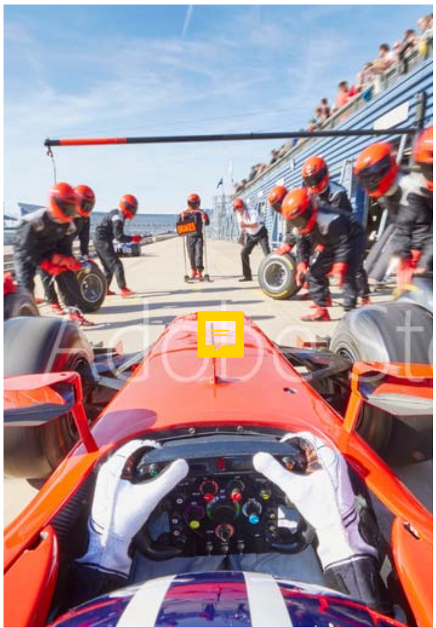
Formula E is unlike any other motorsport, and not just because it is a well-established global series for electric cars. Designed as both a pathway to sustainable racing and a high-pressure laboratory for electric vehicle technologies, its ethos, objectives and technology roadmap require a different focus to traditional top-level competition. Fortunately, it also requires a different level of budget, as the rules are set to minimise areas where a big spend can deliver a faster lap.

To keep costs down, most of each car is manufactured by a single supplier to a single specification. The key exception, and increasingly so as the rules evolve, is the complete powertrain; from battery, power electronics and energy management to the motor and increasingly ambitious systems for kinetic energy recovery.

With the podium spotlight firmly on brilliant powertrain engineering, each incremental improvement becomes a potential race winner. Competitive advantage must be won through understanding the nuances of every system's performance and the complex relationships that define how they work together. For powertrain engineers, the challenge begins with understanding those nuances and their impact on performance and efficiency. That requires a quality of detailed, high-resolution data that cannot be supplied by conventional test systems.

This white paper considers the areas of powertrain data that will enable competitive advantage in Formula E and presents a fast, affordable route to delivering that data. It looks at the opportunities and challenges presented by the transition to Gen 3* and discusses areas where further research is needed to establish how to deliver the greatest performance improvements. With a growing range of new electric motorsport series, alongside the planned electrification of established series such as the FIA's World Rallycross Championship, these capabilities will become increasingly valuable to the motorsport community.

With the COVID-19 pandemic having postponed a number of races and pushed back the introduction of more open regulations, now is the time to search for a race-winning advantage.



'THERE ARE FEW AREAS FOR TECHNICAL DIFFERENTIATION, SO EACH ONE MUST BE THOROUGHLY UNDERSTOOD AND RIGOROUSLY EXPLOITED'

* At the time of writing, the regulations for Gen 3 are still being developed. This document is based on a thorough review of the best information available together with input from the FIA.

FORMULA E OVERVIEW

It is often assumed that Formula E is simply an electrified version of conventional motorsport, but that's missing the point of this well-thought-out series. As a new concept from the ground-up, Formula E has successfully thrown away the baggage associated with many long-established race formulae, as well as the power struggles and politics that can make traditional motorsport as challenging off the track as it is on.

What makes Formula E stand out is that it is not just designed as motorsport for the business owners and competitors, but as a set of technical, environmental and social objectives that are delivered through racing. It takes advantage of its clean, quiet powertrains to run exclusively in cities, bringing electric motorsport to the people and making it easily accessible. To reduce costs and minimise its CO2 footprint, it mandates all-weather tyres of a single specification so there is no need to ship a variety of treads and compounds around the world. Even the electricity used to power the cars is 'clean', having been created on-site by machines the FIA calls 'glycerine fuel generators' – conventional generators running on glycerine produced from 100% renewable materials.

The programme began cautiously in 2014 with cars that were mechanically identical: teams were only allowed to tweak their cars' set-up and adjust the software that controlled the powertrain. Having proved the basic concept, Season Two introduced competition amongst the engineers with teams now able to develop their own motor, inverter and gearbox. Not all were successful, but a lot was learnt to the benefit of later seasons as well as future battery electric road cars.

In common with road cars, range is one of the core challenges. For the first four seasons the solution was rather clunky: a mid-way car change. Clearly having an extra car, with its travel costs and environmental footprint, was not in-line with the environmental objectives of the series and did little to persuade the audience that range anxiety should not be a barrier to driving electric domestic cars. This was addressed with the introduction of the second generation cars (known as Gen 2) for Season Five.

Gen 2 cars introduced a totally new design, with more aggressive looking bodywork to please younger audiences, a new chassis and a new battery pack that while similar in size and weight to the previous generation system, provides sufficient energy density for cars to race 'flag to flag' without the awkward change.

Each year there are subtle tweaks to the regulations aimed at closing loopholes or improving the sport, but we are essentially still racing with the Gen 2 cars. The exciting news is the imminent launch of the technical specifications for the all-new Gen 3 cars that are currently expected to arrive at the starting grid at the end of 2022 for the new 2022/23 season. With more power, more design flexibility, aggressive regenerative braking and ultra-fast charging, these cars take a big and exciting technical step forward both for the series and for the road car technologies that they precede.

Road car laboratory

In the Invitation to Tender for Gen 3 supply contracts, the FIA and Formula E Holdings reaffirmed that they are aiming 'to keep positioning the Formula E World Championship as the laboratory of cutting-edge technologies for electric (road) cars.' While it may not be 'the' laboratory, it is certainly an increasingly important innovation driver and proving ground for battery electric road car systems and can already claim several examples where the series has previewed technologies now available in production vehicles. Just as important and equally valuable, it has also allowed exploration of technology strategies that have proved less successful.

The interest starts with the deployment of multispeed transmissions. We are yet to see any indication of a five speed EV transmission for a road car, but that is how Formula E launched (although the ease with which a commercially available five speed manual motorsport transmission could be adapted was a significant part of that decision). Towards the end of Gen 1, the regulations shifted to allow teams to design their own gearboxes, typically choosing between one and three ratios. By Season Five, every team had eliminated the weight and complexity of additional gears and moved to a single speed transmission. Intertek has supported a number of multispeed road car programmes, investigating durability, refinement and their impact on motor efficiency for different drive cycles, but so far applications are limited to niche models and two speeds.

This was also an interesting time for power electronics as by Season Four, all Formula E teams were employing inverters based on SiC MOSFET switches that can switch more current at higher frequencies than the previous generation silicon switches. They can also run hotter, so need less cooling, allowing smaller radiators that reduce aerodynamic drag. SiC inverters are currently employed in some high performance, premium electric road cars and will inevitably become more common as costs come down because they allow a significant increase in powertrain efficiency. A similar path is described by Formula E battery packs, which from Season 5 were uprated from 693 volts to 880 volts, allowing higher efficiency motors. Again, Intertek is seeing a similar trajectory in road car programmes that it is supporting.

The transition in battery design has also proved interesting. Gen 1 packs employed pouch type cells, each one about the size of an A4 padded envelope. Controlling cell temperature is essential to ensure efficiency and durability and this topology was thought to improve thermal stability via the cooling plates positioned between the cells. For Gen 2, a review of commercially available technology led to a switch to small cylindrical cells that could be more tightly packaged: one of the major contributors to the increased energy density that allowed 'flag to flag' racing on a single battery. Cooling plates now zigzag between offset rows of cells, connected to external manifolds and radiators to cool the oil-based dielectric fluid. The battery pack casing is constructed from carbon fibre with external Xylon anti-intrusion panels; an area where Intertek specialists have contributed to understanding the crashworthiness of the equivalent road car components.

Planning to win

The Formula E race calendar normally begins in November and continues through to August the following year. Season 7 (2020-21) was set to be a big year for the formula, with the arrival of FIA World Championship status marked by a much more flamboyant body design. Known as Gen 2 EVO, this update was designed to make the cars look more exciting but would have led to significant costs for the teams. As both the race and development calendars came under pressure from Covid-19, the FIA decided to cancel this evolution and move directly to Gen 3. Season 7 is still happening, but with Gen 2 technical regulations and although still referred to by the FIA as 2020-21, it begins with the Diriyah E-Prix at the end of February 2021. The revised schedule means that Season 8 will also race under the Gen 2 regulations with Gen 3 cars arriving for Season 9 at the end of 2022.

Removing the intermediate step-up in the regulations retains the competitive focus to the powertrain. While some teams have announced new powertrains for Season 7, most are seeking competitive advantage from clever incremental improvements across each of the powertrain systems. These will have to be well conceived, as announcements from the teams planning new systems are using confident phrases such as 'game changing'. The regulations allow each manufacturer just one major change to the specification of the MGU (Motor Generator Unit), battery and inverter each year, plus minor tweaks through the season, so whether a team takes a big step or focusses exclusively on continuous improvement, winning the technology race will mean seeking deeper insights into every aspect of every powertrain system and how they work together.

One of the most important challenges is efficiency, which is intimately linked to the development of strategies for managing the limited energy available to the car. Intertek is already working with Formula E clients to characterise energy consumption through the drivecycle, helping the teams plan how to deploy the available energy throughout the race. Integrated within this research can be the identification of areas of energy consumption that will respond most effectively to further technical refinement.

Then we have the substantial, exciting step that comes with Gen 3. Already, teams and technology suppliers are thinking carefully about the new opportunities and how powertrain innovation can help secure a podium finish. At Intertek, we have on-going research programmes that will lead to new technology development and, our clients believe, to victory at the chequered flag.

'BRILLIANT POWERTRAIN ENGINEERING IS AT THE HEART OF EVERY WINNING ENTRY'

THE TECHNOLOGY RACE

A focus on energy

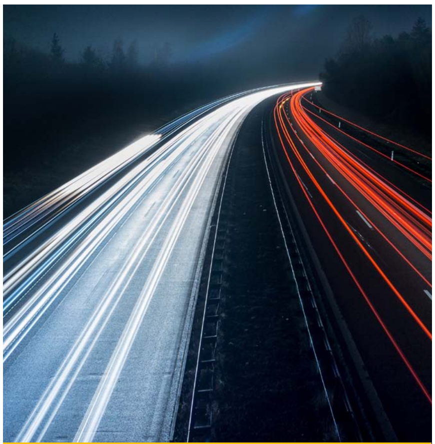
In most combustion engine motorsport, the organisers specify design parameters such as cubic capacity, allowing engineers to employ their creativity to deliver the most useable performance. Formula E, however, specifies both the maximum power and the total energy available to the Motor Generator Unit (MGU). The focus is very clearly thrown on efficiency: how to use the available energy to maximum advantage.

This is reflected in the regulations, which allow far greater flexibility in the design of the MGU, Inverter, DCDC Converter, VCU (Vehicle Control Unit), powertrain cooling, wiring loom, driveshafts and final drive than is possible in the rest of the car. It's a clever strategy that reduces costs for the teams while focussing R&D on areas that will be of greatest benefit to the racing and to future road cars.

The engineering challenge is multiplied by the growing demand to find the right solution before racing begins. In October 2020, the FIA released a set of additional requirements aimed at reducing costs by further restricting the changes allowed to homologated components through the season. The number of spare parts is to be even more tightly restricted, requiring component durability far in excess of that generally required for top level circuit racing. Data acquisition is to be confined to a 'certain number' of sensors on the car to reduce the amount of analysis between sessions, limiting through-season information for prognostics and design improvement.

The emphasis falls dramatically on rigorous pre-season development and testing to ensure components are fully optimised for performance and durability from the very first race of the season.

Even without an opportunity to make fundamental changes, substantial benefits are available from the cumulative effects of incremental improvements and from a more detailed understanding of how to deploy the available energy. The key to delivering these improvements is the availability of a full spectrum of high-resolution data, particularly at the extremes of performance. In motorsport, especially Formula E with its restrictions on in-season design changes, understanding the edge cases is vital. To reduce risk, this must be achieved for every design change before homologation.



'TIMESCALES ARE DEMANDING, MAKING FAST, RESPONSIVE DEVELOPMENT TESTING EVEN MORE ESSENTIAL.'

Gen 3 brings new opportunities

Generation 3 is where the real excitement begins. Having taken a substantial step towards offering teams control of their powertrain designs with Gen 2, the new regulations will introduce not just more freedom to fully exploit existing technologies, but also the possibility of introducing some important innovations that will fully live up to the FIA's claims for Formula E as a laboratory for road car R&D.

Looking hard at their environmental goals, the FIA has also taken a prescient step in requiring a full Life Cycle Assessment of each homologated design. With the road car industry waking up to the whole-life social and environmental challenges of electric vehicles, notably those with large battery packs, this is yet another bold initiative to accelerate the development of skills and capabilities that will help inform the responsible introduction of electric road cars.

In a press statement, the FIA said 'Manufacturers must propose a full Life Cycle Assessment for their proposed car, with challenges made on the use of sustainable materials, the lifespan of consumables, recycling and second life projects for used components and more. And they will be required to investigate the lifespan of all wearable parts.'

A significant power increase will take the Gen 3 cars to 350 kW for qualifying and 300 kW in racing (up from 250 kW and 220 kW in season 8), while the battery pack is reported as dropping from 54 kWh to 51 kWh, although at the time of writing it isn't clear if this will be total capacity or useable capacity. Charging can be at up to 600 kW – astonishingly fast by road car standards. The FIA says that fast charging will be used to create 'more exciting and unpredictable racing,' potentially because with smaller battery packs, the cars may no longer be able to complete a full race so will have to return to the pits for a 30 second charge boost.

Regen will be at the same impressive rate, up from 250 kW on the Gen 2 cars and now provided by the front axle as well as the rear, although only the rear will be used for traction. With the rear axle contributing up to 350 kW (and the front contributing 250 kW), the lighter Gen 3 cars will break new ground by not having friction brakes at the back.

For engineers, the implications are clear: competitive advantage remains focussed on the powertrain. The winning powertrain will be the one that uses the available energy most efficiently and combines this with appropriate robustness from the first flag down. Component performance and durability must then be validated across a representative drive cycle that accommodates the range of often extreme conditions experienced by the car and the powertrain.

While draft regulations have been released for some areas of Gen 3 technology, at the time of writing much of the detail is yet to be confirmed, so this discussion should be read in that light.

'FINDING INCREMENTAL DESIGN IMPROVEMENTS REQUIRES GREAT PRECISION SO THAT SMALL EFFECTS CAN BE STUDIED REPEATABLY.'

WINNING INSIGHTS

New centre of excellence

Evolution in the regulations clearly introduces additional test system challenges: not only must each powertrain system be understood and optimized at component and subsystem levels; all of their interactions must also be understood and optimised in the quest for winning incremental improvement. There is then the increasingly demanding component life requirement and the possibility of a sustainability audit.

Fortunately, test systems designed for next generation road car EV research, combined with test strategy insights from experienced vehicle electrification specialists, offer a fast, affordable solution. One of the most advanced centres of expertise is close to completion in the UK, where Intertek, Europe's largest independent specialist in powertrain test and certification, has invested in a new, purpose-built EV/HEV powertrain test facility specifically to answer these complex questions within exceptionally demanding timescales.

Motor generator unit

The search for powertrain efficiency improvement typically focusses on novel motor architectures, improved magnetic design (e.g. by reducing the air gap in IPM motors), more effective thermal management and improved control strategies and technologies. For example, improving the properties and application of magnetic materials allows thinner laminations that can reduce eddy current losses, but this can only be achieved with a robust understanding of the impact of change on their durability and high temperature stability.

The challenge is compounded by the parallel trend to increase power density by increasing spin speeds. Today's production motors typically operate at up to 15,000 rpm with Formula E motors typically reaching around 20,000 rpm. Intertek is already working with clients on speeds up to 25,000 rpm and is installing test systems rated for E-Machines operating at up to 27,000 rpm, with higher speeds already planned. At these speeds the test challenge isn't just about the physical test system: data capture at a meaningful resolution must also be carefully considered (see side panel), a challenge amplified by the very aggressive transients that will be experienced by a Gen 3 powertrain snapping from full traction power to full regen. Even with today's powertrains, this latter characteristic is also a challenge for the dynamometers, which must have very low inertias to ensure there is no test system limitation on the ability to reproduce the unparalleled rates of change in speed and torque in both directions.

This is an area where an experienced test engineer is essential, also because the ways in which the battery pack and power electronics react to these transients can have a significant impact on MGU performance, so must be highly representative during testing and thoroughly understood to allow effective design optimisation. Expertise is also the key to delivering an accurate efficiency map, especially when correlated against the temperature of sensitive components; on those rare occasions when there is access to the measurement point, fitting and routing the sensor could adulterate the results.

One area where road car engineering is ahead of Formula E is the development of highly integrated Electric Drive Units that combine the E-Machine, Power Electronics and Transmission in a single, highly optimised unit. While the packaging and cost benefits may not be critical to Formula E, the potential for substantial efficiency gains is very much of interest. Each step towards more efficient integration requires not just a deeper understanding of each system, but also of their interfaces and interactions; for example, the additional EMC issues and the question of how to most efficiently manage the thermal requirements of such diverse systems.

While a fully integrated EDU is unlikely for next-generation Formula E cars, there are lessons that can be learnt and applied when assessing Gen 3 powertrain architecture choices. Intertek is already working with Formula E constructors to characterise complete powertrain systems, including the MGU, transmission and power electronics, helping the company's clients develop a complete understanding of system efficiency, interactions and dependencies.

With increasing integration and vastly greater thermal and mechanical stresses, there is an increasing recognition that developments in lubricant technology will also be vital, both in enabling other technology developments and in creating a direct benefit from reduced friction and parasitic losses. There are several challenges. As machine speeds increase, energy losses can become substantial if not carefully managed, and losses also mean heat. The fluid is not just a lubricant, but in the MGU is also the main cooling mechanism so must have a high heat capacity and resistance to damage by hot spots. And, as the voltage rises, the fluid's dielectric properties become increasingly stressed. Intertek's network of laboratories includes the facilities and expertise necessary to accelerate the development of these new generation fluids and to define and deliver the characterisation necessary to support powertrain development.

Thermal stresses also require an understanding of the heat flow patterns seen in the MGU (and other powertrain systems) during a race, and especially the identification and evaluation of any hot spots. With nothing available commercially that could provide the necessary rates of heating and cooling for MGU testing, Intertek developed its own system, able to deliver up to 9 kW and absorb up to 30 kW. The high performance of this system has already allowed teams not just to more accurately replicate race conditions for system development, but also to understand and optimise efficiency during the warm-up period.

Across all these areas, especially materials selection and manufacturing techniques, new approaches must also consider the need for end-of-life recycling. The potential requirement for a Life Cycle Assessment (LCA) suggests a need to reduce dependency on expensive magnetic materials that may have unstable or questionable origins and to ensure they can be returned to the supply chain at the end of their component lives. Much can be achieved through materials substitution, such as finding alternatives to the heavy rare earth metals that are added to improve the temperature resistance of neodymium, and through efficiency improvements that reduce the requirement for these materials; but again, rigorous validation of design changes is required within the compressed timescales.

Test Requirements

Our analysis of the test requirements for E-Machines for Formula E has identified the following areas where advanced test techniques will help to facilitate progress in system technology:

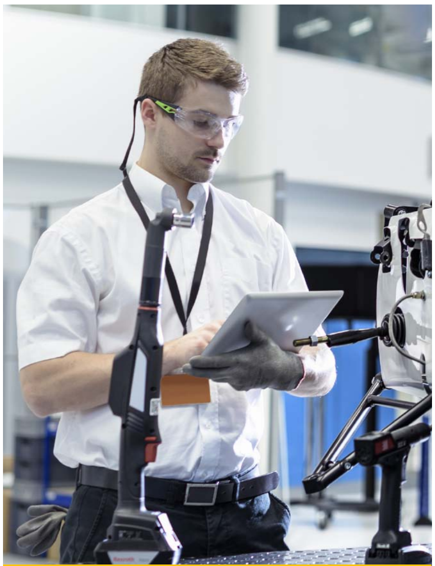
- Very high-speed operation
- Very high wheel torque with aggressive transients
- Thermal management including hot spot mitigation
- Integrated cooling loops for the mandated media
- Different cooling loop topologies and airflows
- Migration from three phase operation to six or nine phases
- New magnetic materials and their impact on efficiency and durability
- EMC
- New e-machine architectures
- Durability measurement and analysis
- Lubricant characterisation and analysis

As with all automotive test operations, these must be explored across all likely operating conditions, from extreme heat to extreme cold, dust, salt, vibration, physical shock (through the suspension) and driver abuse. Even with highly skilled professional drivers, the differences in mechanical sympathy can be alarming.

Finding incremental design improvements, particularly at high motor speeds, requires great precision so that small affects can be studied repeatably. For this reason, direct drive e-machine dynamometers are preferred; a technology that Intertek has been driving forward with its test system suppliers, with particularly demanding requirements satisfied by in-house development.

There is also additional complexity in the energy supply for MGU testing. For combustion engine testing, fuel is generally of consistent specification (if we ignore the challenges of poor fuel quality faced in a surprising number of markets) and although volatile, is relatively safe to store and handle. Batteries have a different range of issues, including failure mechanisms that can be hazardous. For this and other reasons, in a test environment the propulsion battery is generally replicated by a battery emulator: a system that provides the required voltage and current directly from the supply, without chemical storage.

This approach also eliminates the variability associated with chemical storage, allowing much more repeatable results, but it does require an accurate understanding of the battery characteristics and the responses and strategies of the Battery Management System. Changes in current, for example, can be fast and substantial, so the emulator must precisely replicate the response of the battery system. It must also be able to cope with variable inductance loads whilst maintaining tight control of voltage to prevent over or under-shoot from target voltage set points. At its new test centre, Intertek is installing battery emulators that at the time of specification were the most advanced available from any supplier.



DATA HANDLING

High speed motors require very high-speed data collection (into the MHz range), alongside the need for considerable flexibility to accommodate a wide range of sensors. The challenge is to collect and manage this data efficiently, quickly and at reasonable cost.

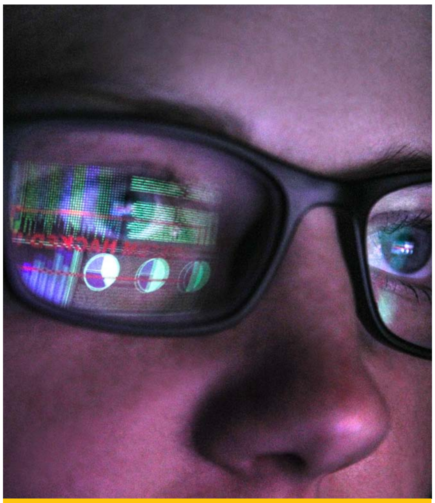
The solution is a combination of high-performance design of the control and data acquisition systems, intuitive graphical user interfaces and development environments that eliminate the need for low level programming. This approach allows fast, multichannel data collection, storage and processing to maximise the range and quality of information achieved from each test.

At Intertek, this approach is applied across all major test systems and clients can have data access and supervisory control from anywhere in the world.

With Gen 3 introducing exceptionally high energy flows in both directions, with very aggressive transients as cars switch from full power to full regen, results will only be fully representative if the battery emulator can accurately simulate how the battery pack and BMS will respond. Intertek's new emulator is therefore the first in the UK to be built around high-speed SiC MOSFET switches, allowing precise emulation of the battery in race conditions, with faster response and less current ripple than conventional emulators and an ability to supply current at a uniquely representative rate of >1 MW/ms.

The skill required from the test engineers is therefore not just in the development of a bespoke, high-precision test system that accommodates the requirements, but also in understanding how to specify the test conditions and parameters to accurately reflect real-world usage. An example is energy losses caused by movement of the fluids used for cooling and lubrication. Intertek found that with no third-party technique available, investigation required the development of a bespoke test system, using a custom twist beam sensor to provide torque measurement to +/- 0.001 Nm. To ensure correlation with real-world usage, Intertek has also developed a bespoke oil conditioning system and a novel technique for heating the stator that contributes to making this a unique test capability. Another example is the measurement of spot temperatures, which can require non-contact temperature sensors with galvanically isolated data acquisition systems.

The same approach is used to ensure that each test programme delivers the maximum possible value for the client by gathering as much useful data as possible from each test. In Formula E, value will include a large element of time compression. E-Motor test systems, for example, can include measurement of NVH (Noise, Vibration & Harshness) and non-intrusive infrared measurement of bearing and rotor temperatures. It is also valuable to take high fidelity power analysis measurements as characterization of power consumption early in the design phase can provide invaluable support for the development of other systems.



'RACE-WINNING SYSTEM OPTIMISATION REQUIRES EXCEPTIONALLY HIGH-FIDELITY DATA'

BATTERY (RESS)

With Formula E batteries (known as the Rechargeable Energy Storage System) provided by a single supplier to a single specification, it could be concluded that little additional knowledge is required, but in the search for competitive advantage this is of course wrong. Teams are allowed to rework the way the software controls energy utilisation, so have flexibility to manage the temperature, current profiles and other factors that affect RESS performance and reliability over its demanding full-season life. A deep understanding of the battery characteristics is therefore essential, alongside careful validation of the chosen strategies for ensuring system durability.

This is particularly true with the introduction of the new RESS for Gen 3: not just a different design from a different supplier, but a smaller, lighter unit (down from 284 kg to 180 kg) with the slightly lower capacity previously discussed. Despite this scaling down, it must reliably handle the huge step up in both power delivery and charging rate, including fast charging and unparalleled levels of kinetic energy recovery throughout a very aggressive drive cycle.

Test Requirements

Our analysis of the test requirements for batteries has identified the following areas where advanced test techniques will help to facilitate progress in system technology, within the limitations of a fixed design RESS unit:

- Cycle life analysis including the impact of thermal cycling regimes
- Hybrid Pulse Power Characterisation
- Thermal management using a choice of media
- Climatic conditioning and rapid temperature change
- Fast integration of prototype BMS and control software
- Very high-speed data collection
- Comprehensive understanding of EMC issues

Additional areas for the pack developer:
- Cell, Module and Pack level capability
- Physical robustness and safety
- Electrical abuse and safety

The first test challenge is to ensure that the interactions between the E-machines (which for Gen 3 must include the front energy recovery system), the power electronics and the electromagnetic environment are all representative of race conditions and drivecycles. This includes how the heat generated by extreme current flows is managed.

While the operating range for the new RESS could be around 30° C, the cells are at their most efficient within a window of just 10° C. If a cell overheats, the BMS will derate the some or all of the battery to ensure there is no 'thermal event', ie a fire. Clearly, a race-losing situation. Control strategies and thermal management, to extract maximum efficiency without compromising durability, are central to success, but such is the temperature sensitivity that very precise correlation with real-world temperatures profiles is essential.

When these test system requirements have been achieved, research and development can focus on characterising the RESS performance and behaviour across the full range of demands and understanding how this affects the performance of other powertrain systems.

'IF GEN 3 ISN'T PUSHING HARD AT THE LIMITS OF YOUR TEST TECHNOLOGY, YOU'RE MISSING OPPORTUNITIES TO GET AHEAD'

POWER ELECTRONICS & BMS

Power Electronics, including the energy management and the powertrain control software, are a fundamental area of competitive advantage and one of very few where the teams have an ability to innovate. Not surprisingly, it is seen as one of the most important areas for technical advantage. However, as with the RESS, the exceptional energy flows and spiky transients create a very harsh environment, making robustness and effective thermal management two challenging partners to winning control strategies.

The transition to Silicon Carbide MOFET switches for Gen 2 has eased the burden of thermal management within the inverter, but because these now run hotter, it has also created additional challenges when managing the temperature of components that are at their most efficient when running cooler. For Gen 2, teams typically relied on a cooling circuit shared with the MGU, in which a water / glycol mix was electrically pumped through a radiator in the left hand sidepod. Reviewers have commented that the size of the radiator indicates the team's success in maximising powertrain efficiency as excess heat is energy wasted that could be driving the car. A smaller radiator also improves aerodynamics, so as with many areas of powertrain design, improvement in the primary function leads to secondary gains too.

While there will be opportunities to apply learning to the software package throughout the season, the change in regulations will require the VCU (Vehicle Control Unit) software to be homologated seven days before each race meeting. For Gen 3, the software specification for the entire season must be declared before the championship begins. At the time of writing, however, some of the parameters to be determined by the regulations are yet to be defined.

Test Requirements

Our analysis of the test requirements for power electronics has identified the following areas where advanced techniques will help to facilitate progress in system technology:

- Flexibility to address voltages up to 1,000 V (the current cap) and beyond
- Scalability to address future power increases
- Thermal management using a choice of media
- Migration from three phase operation to six or nine phases
- Fast integration of prototype control software
- Very high-speed data collection
- Comprehensive understanding of EMC issues

Even by vehicle electrification standards, the rate of progress of Power Electronics technology is impressive. For test engineers, this is a significant challenge that requires very high levels of flexibility and scalability to ensure new technologies, as we may see for Gen 3, can be quickly accommodated; in-house system customisation of test systems is vital to eliminate the time lag introduced by dependence on a specialist supplier. With very little historical precedent to help design test programmes, the expertise of the test engineer is particularly critical to ensure a representative programme that addresses the relevant design criteria.

Ensuring a test accurately reflects real-world operation also requires attention to be paid to the test environment, especially to minimize electrical noise and electromagnetic interactions that are not representative of those that will be experienced in the vehicle. The interaction of the motor with the power electronics is complex, requiring precise, high-speed power analysis for accurate characterisation and again, an experienced test engineer to ensure the total system is fully representative. Data recording at up to 200 kHz allows high resolution power analysis, while AC wave cycle analysis can be in the GHz range.

Another factor critical to correlation with real world operation is temperature. Intertek has found that there are currently no commercially available coolant conditioning systems that meet the demanding requirements of Formula E power electronics, so has developed its own system capable of handling a range of media and flow rates to ensure representative thermal gradients and spot cooling.

WHOLE VEHICLES, TRANSMISSIONS AND DRIVELINES

Taking the motor speed to 20,000 rpm and beyond creates additional challenges for the vehicle transmission and driveline. But, where there is a challenge, there is always an opportunity to find a more efficient solution than the competitor teams.

Multispeed transmissions are thought unlikely to return for Gen 3, which means very high shaft speeds entering a highly geared reduction transmission. A deep understanding of the stresses and resonances that this creates will be essential, especially as there is very little prior research at such high motor speeds. For the coming seasons, the emphasis will be on incremental improvements in seals, bearings, gears and lubrication where energy can be saved by reducing friction. The development of new cars for Gen 3 allows considerable opportunity for innovation, with several areas to consider including more efficient lubrication strategies (to reduce oil spin losses) and new, more integrated architectures. There are also opportunities to move to more innovative lubricants: low loss fluids will make a growing contribution and Intertek is already conducting some interesting research with the oil and additive suppliers.

'THE HIGH CURRENT FLOWS IN EACH DIRECTION ADD THE COMPLICATION OF BACK EMF AND OTHER EMI ISSUES THAT CAN HAVE A WIDE-RANGING IMPACT.'

Test Requirements

Our analysis of the test requirements for whole vehicles, transmissions and drivelines has identified the following areas where advanced test techniques will help to facilitate progress in system technology:

- Drive cycle analysis including torque pattern characterisation
- Noise, Vibration and Harshness
- System and subsystem efficiency
- Lubrication and cooling system losses
- Fast integration of prototype control systems and software
- Very high-speed data collection
- Precise analysis of component performance
- Comprehensive understanding of EMC issues

Early electric vehicles, without regenerative braking, could be tested on a conventional chassis dyno as the energy flow was one way. Since the introduction of regenerative braking, specialist dynamometers are required to provide fast modulation of positive and negative torque. The high current flows in each direction also add the complication of back EMF and other EMI issues – to an as yet not fully understood level with Gen 3 levels of regen.

The next step, already implemented at Intertek and ideal for Gen 3 vehicles, is the introduction of hub dynos. The many advantages of this technique include:

- Increased consistency through direct engagement with the driveline, removing variability, tyre slip and strap tensions
- Precise transient responses, e.g. to measure wheel slip
- Ability to measure speed differences across each axle
- Low inertia allowing accurate simulation of highly dynamic drive-cycles

A well-designed test centre should also offer two or four-wheel drive capability (useful with Gen 3 regen on both axles) and the ability to operate E-Machines at different voltages on each axle. Surprisingly, rig stiffness can also limit data quality as very high transient torque loads place tough demands on equipment reliability and must not be allowed to introduce inaccuracy through unwanted movement in the rig or driveline components. However, too stiff a mounting may be equally unrepresentative.

In many component and system tests, too stiff a mounting can be as unrepresentative as a rig that is too flexible, as distortion due to torque or vehicle dynamics can impose significant additional inputs that must be reproduced. Intertek has therefore developed a technique for carefully designing component mounts to ensure a close correlation with the physical behaviour during a race.

NEW FACILITY FOR ELECTRIC MOTORSPORT & EV DEVELOPMENT CENTRE OF EXCELLENCE FOCUSSES ON PRECISION TESTING OF NEXT-GENERATION AND HIGH PERFORMANCE ELECTRIC POWERTRAINS

Soon to open in the UK where it can call on the company's experienced electric vehicle test and development team, Intertek's new European Centre of Excellence for precision testing of next-generation electric powertrains is designed from the ground-up to answer the most challenging questions faced by engineers working at the highest levels of electric motorsport.

Experience in Formula E already ranges from delivering component-level insights through to eMotor and eAxle development testing to providing the high resolution analysis of end-to-end efficiency that allows important but subtle optimisation of hardware, software and race strategy. With the introduction of front axle regeneration, even higher speed MGUs and pit-stop recharging, Formula E clients are planning to take full advantage of the next-generation facilities currently being installed.

The new facility will encompass 32 test cells, covering ten different major techniques and a range of subsidiary techniques for the test and development of E-Machines at up to 27,000 RPM, Power Electronics up to 1,100 V, integrated axle modules and on-board vehicle electrical systems. Flexible test programmes will provide insights at component, system and systems integration levels. Complementing the component and systems laboratories, there will be a four-wheel drive, full vehicle climatic test chamber that is believed to be the first independently available EV facility of its type in Europe. Further development is planned, adding battery test laboratories and additional facilities for EV system testing.

Fast and Flexible

The ability to deliver high-quality insights that accurately reflect real world usage is partnered with a focus on accelerating the development process. The new facility is structured for remote set-up so test cells can achieve very fast turnaround, and a high level of automation is specified to allow safe 24/7 operation. Because electrification technology is evolving so quickly, with many questions as yet undefined, there will be a substantial in-house design and build capability so that rigs can be quickly modified, or all new rigs designed and built, to allow new areas of investigation without the delays that can be introduced by dependence on third party suppliers.

Every test cell and laboratory is designed to accommodate the specific requirements of these new technologies. Electrical noise has received particular attention as Intertek's experience suggests it is an area that can have a significant effect on the results yet is often given insufficient consideration. New systems have also been developed to ensure environmental correlation, for example a bespoke climatic soak system that can cost-effectively bring a test system down to -40oC before the test piece is moved to the cell.

Speed and efficiency are also central design objectives for the data systems. Unlike some operations that have grown over many years, the data for each test is held in a single, secure data management system, in a single, time-stamped file. Experienced staff, supported by a dedicated process improvement engineer, ensure that there is no by-passing of this system, no addition of a laptop and sensor set as a last-minute complication that is then difficult and time-consuming to integrate with the main dataset.

Designed from the ground-up to offer genuinely ground-breaking facilities, supported by engineers who understand the difference between test data and race-winning insights, Intertek's new European Centre of Excellence is ready to schedule your electric motorsport programme.

'IN FORMULA E, COMPETITIVE ADVANTAGE CAN BE WON BY UNDERSTANDING THE NUANCES OF EACH SYSTEM AND THE COMPLEX RELATIONSHIPS THAT DEFINE HOW THEY WORK TOGETHER.'

THE INTERTEK ADVANTAGE

One of the challenges with the development of any new technology is the range of expertise required to make it ready for the starting grid. In a relatively new field such as electric motorsport, some of these requirements may be unscheduled, required to answer questions revealed by testing but without time in an already hard-pressed programme.

With more than 1,000 laboratories and offices worldwide, Intertek can provide a complete, end-to-end test programme that can adapt quickly to developing requirements.

Recognising the quality of Intertek's capability, the UK government's South East Midlands Local Enterprise Partnership (SEMLEP) has provided funding the support the development of the new European Centre of Excellence for the testing of automotive electric propulsion systems.

To learn more about solving the test and development challenges of electric and hybrid vehicles, follow the progress of Intertek's state-of-the-art facility on LinkedIn linkedin.com/showcase/intertek-transportation-technologies/.

OUR INDUSTRY-LEADING CAPABILITIES

The new Centre of Excellence will be a hub through which a wide range of complementary specialists are accessed to quickly deliver the complete range of technical insights needed by powertrain engineers with deadlines that cannot be missed.

Intertek's specialists have assessed more than 20,000 batteries for performance, durability and safety. They analyse more than 1,000 oil samples a year, dismantle transmissions and axles to study wear, operate a network of impressive Non-Destructive Testing Laboratories and the world's largest network of EMC test laboratories. Corrosion, materials, vibration, dust intrusion, salt spray and a host of other complementary techniques can be accessed in all major markets, together with laboratories for EV charging and electrical safety.

And the investments in future mobility technology continue, with the recent opening of a brand-new 500-acre facility for the development of autonomous and connected vehicles including heavy duty trucks, ready for the next generation of new automotive technologies.

THE TOTAL QUALITY AUTOMOTIVE INDUSTRY SOLUTION

intertek
Total Quality. Assured.

Assurance, Testing, Inspection and Certification

AUTONOMOUS & CONNECTED VEHICLES
Achieve compliance with all testing and design criteria required to launch your autonomous vehicle solution, including: DSRC testing and certification, ADAS testing, track and road fleet testing, functional safety and vehicle homologation services.

IATF16949, SOCIAL & SUSTAINABILITY
With our services in the field of auditing and certification of management systems (for example ISO 9001, 14001, 18001, 27001, 50001, IATF 16949, IFS, HACCP, BRC, SMETA, supplier audits, etc.), we help you to continually improve your company.

VOLATILE ORGANIC COMPOUND (VOC) & RESTRICTED SUBSTANCE EVALUATION TESTING
We are accredited for material testing by automotive market leading OEM(s) and work with customers on VOC issues to minimize problems before they arise in the field by providing VOC and aldehyde-ketone emission testing for materials and products.

ELECTRICAL COMPONENTS & SYSTEMS
Ensure that your systems and components are compliant with SAE, OEM, E/e-Mark, EMC and other related national and regulatory standards.

VEHICLE TESTING SERVICES
Our in-lab, closed course (track), and on-road fleet testing solutions provide Total Quality Assurance for both passenger and heavy-duty vehicles. We offer mileage accumulation programs virtually anywhere on the planet in any climate, or dedicated time on a closed-course, proving grounds.

COMPOSITES, PLASTICS & METALS
We support developers and manufacturers of automotive materials with expertise in the field of plastic materials, composites, components and metal. Intertek experts understand the behavior and properties of automotive materials and have the latest laboratory equipment and techniques.

FUELS & LUBRICANTS
We are a leader in additive, lubricant, and engine oil testing for standardized gasoline and diesel engines, engine endurance and durability testing, fuel additive & alternative fuel testing, and sealed housing for evaporative emission determination (SHED) fuel system services testing. With comprehensive engine oil testing services, we provide a pathway to American Petroleum Institute (API) engine oil licensing and certification.

ENVIRONMENTAL SIMULATION TESTING
The range of simulated and accelerated environmental testing options we offer brings your automotive products an assurance that they are ready to weather any environmental challenges that may come, rain or shine, fog or humidity, mechanical vibration & shock, or even freezing temperatures and corrosive salt.

ENGINE & eMOTORS
Our testing services for automotive engines and drivetrains help to develop optimal products, and we offer a variety of options for products used in passenger cars, trucks and high-performance engines sectors for gasoline, diesel and alternative fuels.

ELECTRIC VEHICLES, BATTERIES & EVSE
As a world leader in testing and certification of electric vehicles and related charging systems, we are fully invested in the areas of renewable and clean energy. This allows you to bring your products faster to these rapidly growing markets. Including local & global certifications and eMotor validation solutions.

Intertek is a leading Total Quality Assurance provider to industries worldwide. Our network of more than 1,000 laboratories and offices in more than 100 countries, delivers innovative and bespoke Assurance, Testing, Inspection and Certification solutions for our customers' operations and supply chains. Intertek Total Quality Assurance expertise, delivered consistently with precision, pace and passion, enabling our customers to power ahead safely.

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