PROFESSIONAL MOTORSPORT WORLD

pmw

March-June 2017

Next-gen KERS

An in-depth look at the potential for energy recovery from around a competition car

Composites

How composite materials are likely to evolve for motorsport application in the near future

Where to next?

From the development of the next-generation KERS, to potential applications of composites, via improved driver safety and chassis design… *PMW* looks at what the next decade may hold

Interviewed

Mike Dewhirst
Chief technical officer, Lentus Composites

Dr Brian Ingram
Materials scientist, Argonne National Laboratory

Professor Andrew Atkins
Global technical lead and senior technologist, Ricardo

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Recovery position

Kinetic energy recovery systems have been part of the motorsport landscape since 2009. As engineers continue to chase increased efficiency, what shape will future KERS take?

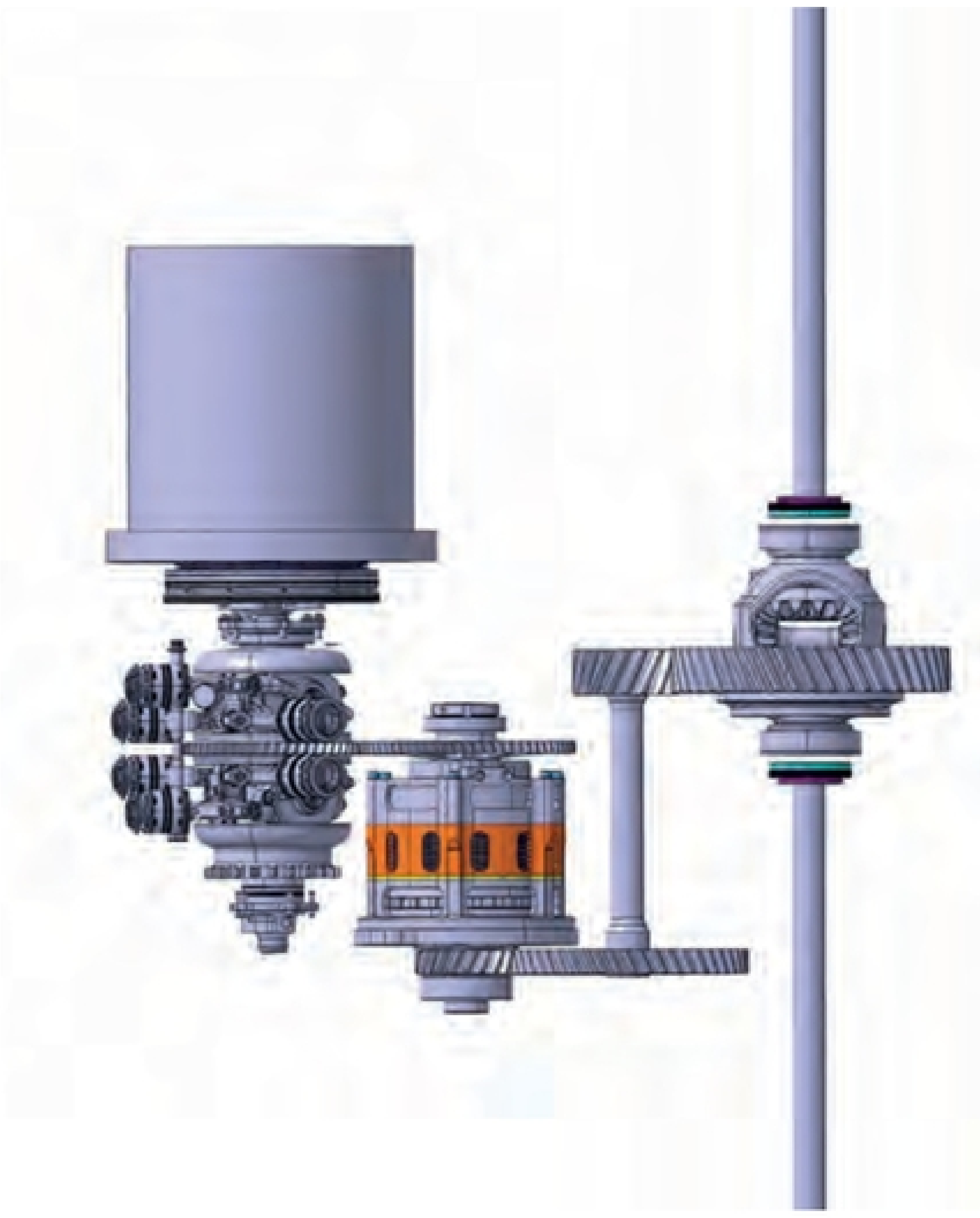
WORDS BY LEM BINGLEY

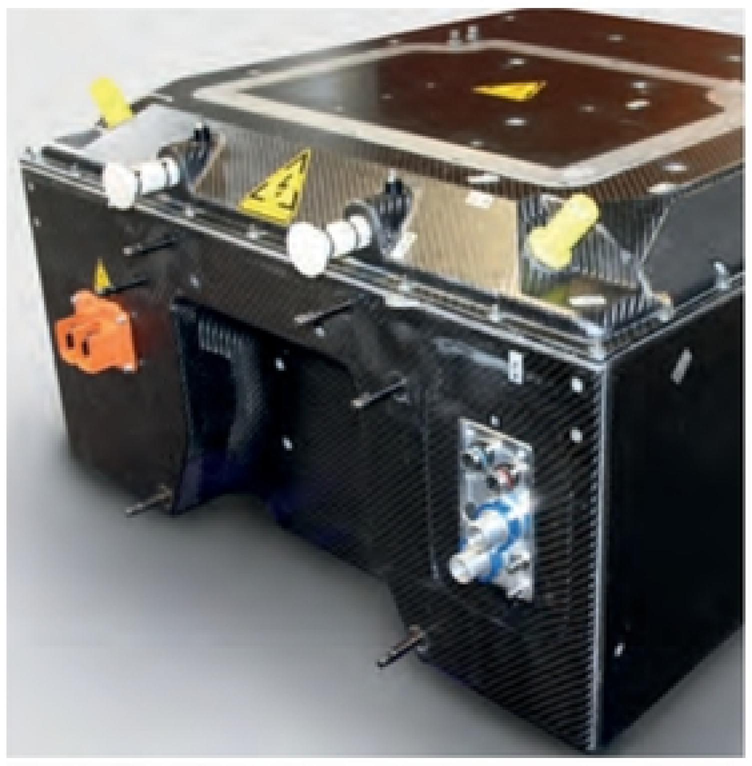
Cars with bright glowing brakes are a familiar sight in racing, as the hard-won momentum of a fast straight is shed going into a corner. But could those blistering discs become a thing of the past? If kinetic energy could be recaptured, stored, and reused to accelerate again, there would be no need for any red-hot rotors.

The prospect of race cars without friction brakes remains a long way off, but grabbing and recycling at least some kinetic energy has been around since KERS landed in F1 in 2009.

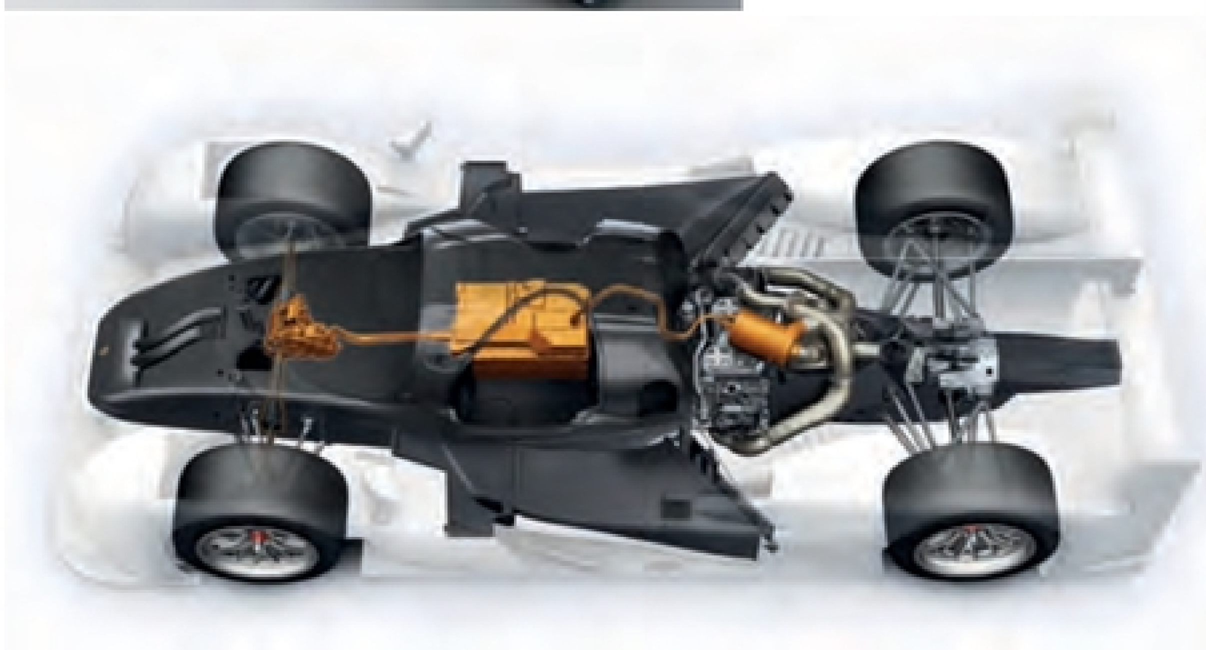
"If you can get hold of energy that's normally wasted as heat and reuse it you're onto a winner," notes Paul McNamara, technical director at Williams Advanced Engineering. "The brakes are the biggest source of lost energy. That's how they work. They convert motion into heat."

When F1 first introduced kinetic energy recovery systems, or KERS, the best way to store captured energy wasn't immediately obvious.





Multiple options of storage have been trialled, such as flywheel (far left)***, but Li-ion batteries*** (above left and left) ***remain the most popular, even in series that allow alternative storage, such as LMP1*** (below)



"We investigated putting it into a flywheel, because of the amount of energy you can store and release versus the weight," says McNamara. "But all the other teams went for electrical systems and so did we in the end."

KERS arrived in F1 with a battery to store energy and a reversible electric machine to act as both generator and motor. It would generate current on the approach to corners, and switch to motor mode to assist the engine on straights – typically during overtaking.

KERS technology evolved into today's MGU-K (kinetic motor generator unit), where an electric machine capable of 50,000rpm is geared direct to the engine's crankshaft. A second motor generator, MGU-H, connected to the engine turbo, also recovers energy from the exhaust.

Current F1 rules allow a 25kg battery as an energy store, fed by the two MGU systems. A maximum of 2MJ per lap can be captured by the MGU-K, while up to 4MJ per lap can be fed back to it from the battery. There are no limits on what the MGU-H can supply to either the battery or direct to the motor.

Despite the sophistication of today's F1 energy recovery systems, other options remain viable and alternative technologies could replace or supplement today's motors and lithium-ion batteries.

While Williams's flywheel never raced in F1, it did assist 2011's race-winning Porsche GT3R and helped Audi Sport's R18 e-tron Quattro to Le Mans victory in 2012 and 2013.

"Basically the choice of energy storage is a compromise between energy density and power density," observes Prof. Andrew Atkins, global technical lead and senior technologist at Ricardo. "The very transient high-power aspects of racing are attractive to flywheels. Speeding up and slowing down repeatedly can be

Formula 1's current hybrid arrangement recovers energy from two seperate elements: MGU-K and MGU-H (below)

Balanced approach

With many race cars powered at the back axle and braking primarily at the front, brake balance is a key facet of getting maximum energy back from the driven wheels. "The danger is locking the front if you lose braking effect at the rear, because your battery gets too full, or you need to avoid over-voltaging the cells, or you have a system failure," notes RML Group's Martin. "You need to be able to put the brakes back on at the rear very quickly."

RML Group designed Nissan's ZEOD RC experimental Le Mans car, built to regenerate sufficient energy to do a full lap of Le Sarthe on batteries. One of the attractions of its unusual delta layout was the ability to apply three-quarters of braking effort at the rear.

In Formula E, active braking systems are outlawed, but the teams still need to ramp up regeneration under hard braking to maximize energy recovery. "You can't insert a calculation between the driver's foot and the rear brake," says Williams's McNamara. "But you can watch the pressure in the brake line and set regeneration levels accordingly. If the sensor says the front is doing a lot of braking, you can wind up regeneration at the rear without it deciding how to balance the two."

Formula E's rules are set for a big change in the 2018-19 season. "They will allow the motor and the brakes to have a control system," adds McNamara. "If the rules changed to allow four-wheel drive, that would be another huge step."

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PROF. ANDREW ATKINS, GLOBAL TECHNICAL LEAD AND SENIOR TECHNOLOGIST, RICARDO

The successful management of a battery's power is becoming increasingly central to racing (above left)

deleterious for batteries but flywheels really like it."

Atkins notes that other purely mechanical systems might also be relevant. "We've looked at compressed air and hydraulic, and for applications outside automotive we've even looked at clockwork," he says.

Capturing and storing energy is only half of the picture, of course. "The other interesting thing is where you put the energy back," Atkins notes. While the common approach is simply to reverse the route from wheels to battery, there are alternatives.

One scenario would be to use an electric motor, like F1's MGU-H, to overrun the turbo. "That partially evacuates the cylinder, which reduces your pumping work, and at the same time rams more air in," Atkins notes. High-pressure air enables a Miller cycle (leaving intake valves open for part of the compression stroke), which cuts compression work. "By reducing both pumping losses and compression work for short periods, the net power output could be increased without increasing the stresses on the engine," Atkins explains.

Another approach would be to use regenerated electricity to pump air into a high-pressure vessel, rather than charge a battery. A similar technique is used by Volvo PowerPulse engines, which release high-pressure air into the exhaust to speed up the turbo from low revs, improving response. Atkins says the more direct tactic of dumping high-pressure air into the intake manifold would also work: "It would be like having a solid-state supercharger."

With the right plumbing, compressed air could be generated direct from engine braking, like a truck's Jake brake. A secondary compressor and a carbon-fiber tank could create "some pretty interesting power densities", Atkins adds.

Arnaud Martin, director of powertrain at racing technology

Bouncing back

Recapturing energy from a car's suspension by making the damper into a linear generator is another way to recover otherwise wasted kinetic energy.

"Regenerative damping is talked about a lot, but it's not energy for free," observes Williams's McNamara. "You see the car bouncing along and think it's going spare, but in the end it's all coming from the motor."

Ricardo's Atkins says that circuit racing offers little potential in this area. "Regenerative damping wouldn't be on my list until I was desperate for the last energy in the system," he says.

Rallies like the Dakar, where the suspension moves a great deal for long periods of time, provide the most promising opportunity. In 2011 suspension firm Donerre built regenerative dampers for Oscar e0, the first plug-in car to contest the Dakar, and the technology is likely to return in the future.

firm RML Group, also backs compressed air. "The components are very simple," he notes. "Energy density is likely to be an issue, but that's where I think motorsports can provide answers."

As Martin observes, the rules set by governing bodies dictate which options are worth pursuing. "They can stop a technology from developing by writing it out of the rules, or prevent one from being implemented because it doesn't leave enough freedom," he notes. "My feeling is hybrid air is something that should be allowed by regulations, and some sort of help given to people considering it."

McNamara, however, is less keen. "Storing compressed gas is always a bit worrying, because it has the possibility of being highly explosive," he says. "If you crack a gas cylinder, the energy is in a really raw form."

McNamara is more enthused by the potential application of supercapacitors, as used by the Toyota TS040 Hybrid endurance race car in 2014.

"One idea is to create a hybrid battery that has both lithium-ion cells and supercaps in it," he says. "The potential advantage is using the relatively lightweight supercaps to handle the peaks and not having to size the lithium-ion cells for that, giving you an overall lighter package."

Martin also sees a lot of potential in supercapacitors but thinks weight and complexity will rule out hybrid batteries. "I would say that in the next three to four years, supercaps will simply overtake batteries in racing," he says.

Atkins is skeptical, however. "Capacitors are great with power, but not so great with energy density," he says. "Graphene is making some inroads and energy densities are getting up to interesting levels, but going from a battery to a capacitor is a fundamental change. You go from a roughly constant voltage source to a constant current source. The voltage of a capacitor goes all over the place with the state of charge, so the power electronics are very different. It's not just a question of getting enough energy in a box.

"Race engineers have to learn an awful lot more stuff than before – high power electrics and electromagnetics on top of all the traditional stuff. We have to find a way to get more people into the system with a much wider understanding of the trade-offs between technologies." <

Nissan's ZEOD (below) ***is capable of regenerating enough energy to complete a lap of the Le Mans Circuit de la Sarthe***

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