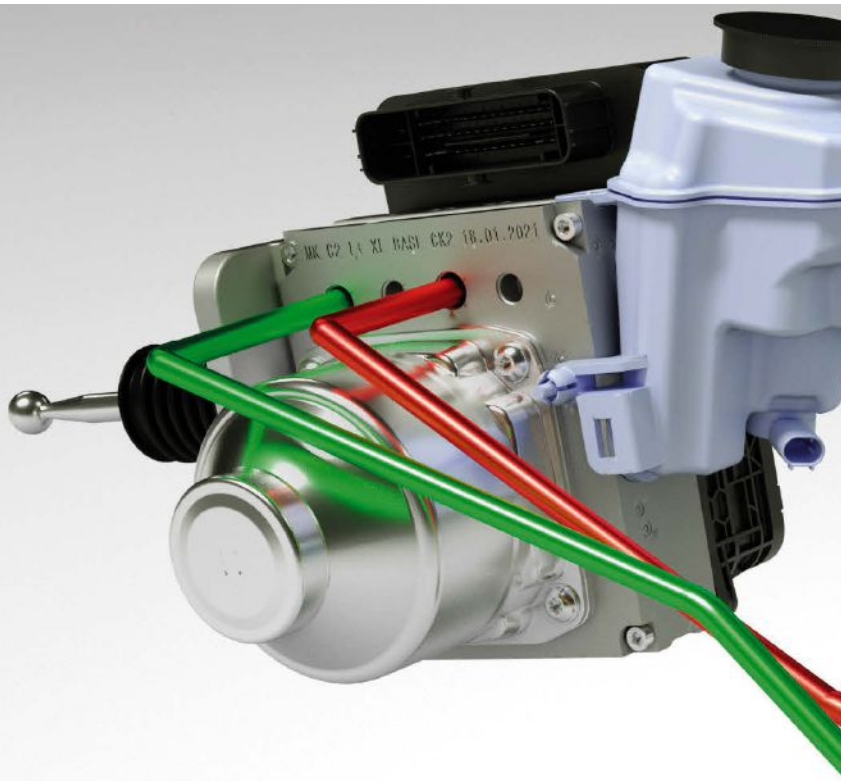


RIGHT: Continental's MK C2 system can be used both with a mechanical pedal (with hydraulic fallback mode) or an electronic pedal (without fallback mode). The system features two printed circuit boards and two processors that can be used to uphold more functions in the event of a fault, such as the parking brake being actuated redundantly. This makes it possible to dispense with expensive mechanical transmission locks

Braking **innovation**

Automotive braking systems have evolved for over a century, but have retained their fundamental principles. But with factors such as EVs, emissions, changes to legislation, and emerging technologies, could a revolution in brake design be underway?

WORDS BY **ANDREW CHARMAN**

In the entire history of the automobile the braking system has formed a vital – arguably the most vital – element of the technical makeup of any vehicle. But over the decades as the technology in road vehicles has mushroomed, braking systems have generally evolved to a familiar pattern.

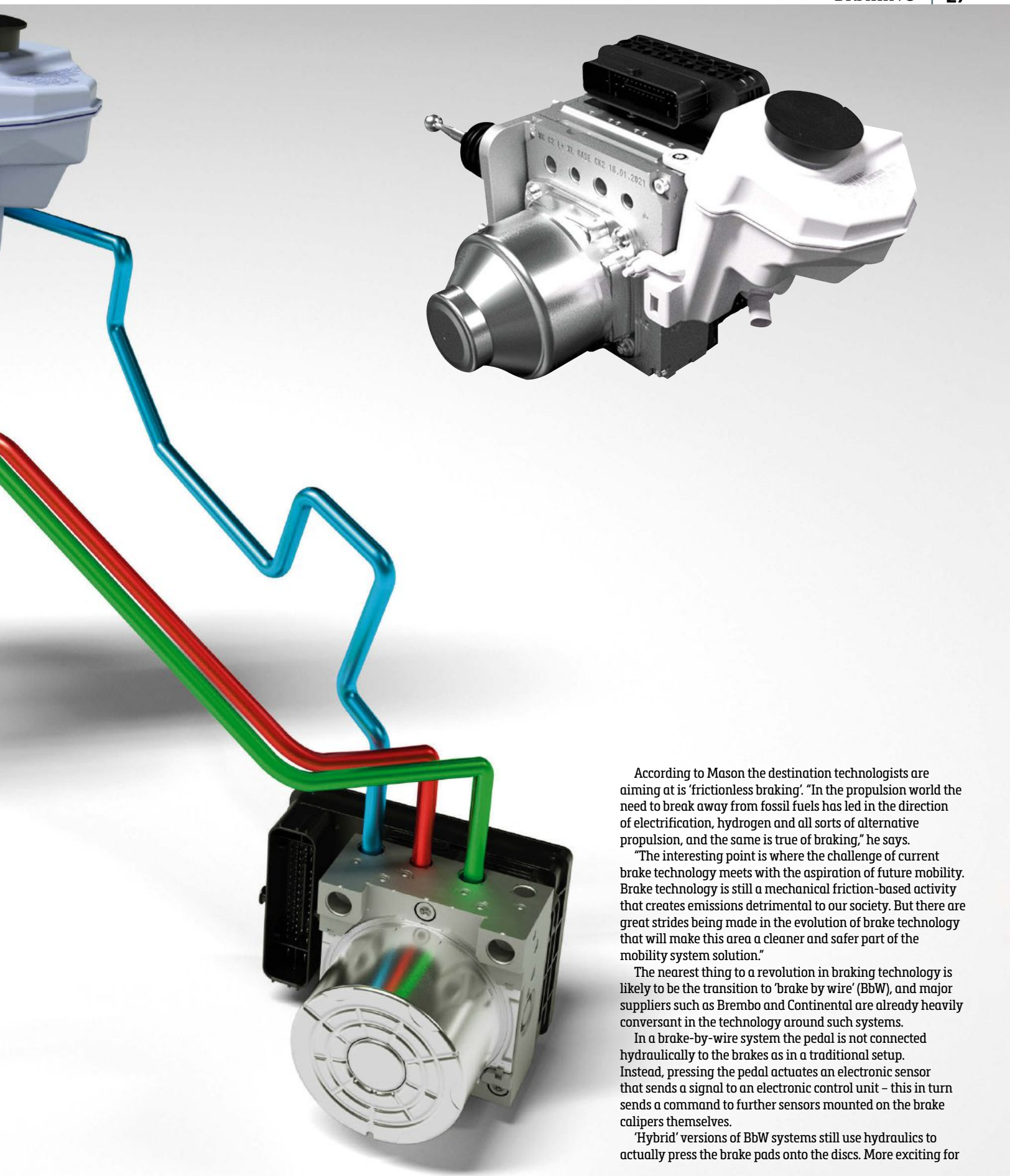
Yes there have been major innovations, for example the change from drums to discs (first seen on the Jaguar Le Mans racing cars of the late 1950s), the arrival of anti-lock systems, and the use of more exotic materials such as carbon and aluminium to supplement iron and steel in calipers and discs. But today's typical braking systems are still based around hydraulic fluid pressing abrasive pads onto rotating discs.

Now, for the first time, we are seeing the emergence of major changes in the way that the momentum of road vehicles is arrested. And many might immediately assume that such changes are being driven by the rise of the EV, on which the braking system has both the capacity and a requirement to generate energy in its operation and pass it back into the vehicle's batteries, increasing the potential range.

In fact, just as strong a requirement driving the reassessment of braking systems is sustainability. 'Green motoring' has fuelled the rise of the electric vehicle, and now that such vehicles have significantly addressed the issue of tailpipe emissions, attention is focusing on all other aspects of the vehicle. Hydraulic brake fluid is not a very environmentally friendly liquid, and furthermore, every time a brake pad presses upon a brake disc, it wears away the surface and creates environmentally unwelcome emissions in the form of micro particulates.

Chris Mason, chief executive of FISITA and organiser of Eurobrake, the world's largest brake technology conference that each year attracts more than 1,250 expert delegates, is well aware of the environmental challenges facing the industry. "Braking is a challenge of technology, always met by technologists, and right now mechanical braking is largely the same as it's been forever – there has been technological advancement over the past 100 years, but primarily to the same principles," Mason tells *VDI*.

"Now we have the challenges of the environment, of legislation, emissions, and a will from society and our industry to meet the net-zero agenda. There have been good advances regarding tailpipe emissions, as a result of which braking and tyre emissions will now have even more focus than ever before – and quite rightly too. We have a corporate responsibility to our planet and the people living on it."



According to Mason the destination technologists are aiming at is 'frictionless braking'. "In the propulsion world the need to break away from fossil fuels has led in the direction of electrification, hydrogen and all sorts of alternative propulsion, and the same is true of braking," he says.

"The interesting point is where the challenge of current brake technology meets with the aspiration of future mobility. Brake technology is still a mechanical friction-based activity that creates emissions detrimental to our society. But there are great strides being made in the evolution of brake technology that will make this area a cleaner and safer part of the mobility system solution."

The nearest thing to a revolution in braking technology is likely to be the transition to 'brake by wire' (BbW), and major suppliers such as Brembo and Continental are already heavily conversant in the technology around such systems.

In a brake-by-wire system the pedal is not connected hydraulically to the brakes as in a traditional setup. Instead, pressing the pedal actuates an electronic sensor that sends a signal to an electronic control unit – this in turn sends a command to further sensors mounted on the brake calipers themselves.

'Hybrid' versions of BbW systems still use hydraulics to actually press the brake pads onto the discs. More exciting for

A drum brake renaissance

In an electric vehicle equipped with a brake-by-wire system, up to 80% of all deceleration events in everyday driving can be covered with regenerative braking. If it is assumed that braking actions are consistently started with regenerative braking, this percentage can be as high as 95%. As a result, for EVs with an optimised regenerative braking strategy, the wheel brakes are hardly used for deceleration, which creates an opportunity to downsize the calipers, saving wheel-sprung mass and contributing to vehicle efficiency.

If the wheel brakes are relegated to being a 'fallback system' for deceleration, only needed in exceptional situations, drum brakes can be a better option than discs. As drum brakes are fully enclosed in a housing, the mechanisms and brake surfaces are well protected from corrosive elements such as rain and salt. And as the brake shoes are retracted from the drum surface by a spring, residual drag is not an issue.

The housing also means that brake dust accumulates within the brake and can be collected in a reservoir at the bottom of the drum rather than being released into the atmosphere. This reservoir can then be emptied by suction-cleaning during a service. Continental has applied this thinking in the EPB-Si drum brake, which is installed on the rear axle of the VW ID.3 and VW ID.4.

Drum brakes can also be suitable for the front axle, as the duo-servo principle achieves high braking torque at low actuation forces. Continental says this makes the front axle drum brake an ideal module for the next generation of dry-operated brakes.

future development is the full 'dry' brake-by-wire setup, in which the caliper is electromagnetic, operated directly by the ECU and dispensing with hydraulics completely.

BbW systems offer a number of advantages for both the driver and the vehicle manufacturer. The brakes are more effective, stable and faster-acting, which increases safety. As the control is entirely electric, the manufacturer can incorporate the braking function into other controls – a prime example already widely used is that a system can momentarily brake individual wheels to aid the car's stability in corners.

Employing BbW systems, which are lighter and more compact, allows a manufacturer more flexibility in designing the layout of a vehicle, while eliminating the hydraulic element saves maintenance and replenishment costs – and of course removing hydraulic fluid has an environmental gain.

"With hydraulic actuation, right now BbW is a hybrid technology, which is how a lot of such technologies come into play," Mason explains. "As we extrapolate that technological process, brake-by-wire concepts will all move to deliver dry systems. The hydraulics are removed, addressing the concerns of the environment."

BbW also lends itself to the regenerative function that is a vital element of EVs, recovering energy to feed back into the battery and increase its range. Levels of regeneration can be individually set, to the point where taking one's foot off the accelerator results in the car's motor decelerating the car, requiring little to no brake pedal input and both preventing abrasive particulates escaping into the air and reducing wear.

"The technologists have worked out that using energy from making things stop can power the forward momentum of those things – that's a piece of engineering genius, a fabulous breakthrough that will deliver for years and years to come that we are witnessing right now," Mason says.

Such scenarios, however, will throw up new potential issues for the technologists to overcome. A typical EV has

ABOVE LEFT: Continental's e-Si drum brake is based on the simplex principle, which offers simple packaging and sufficient braking torque for standard rear-axle applications

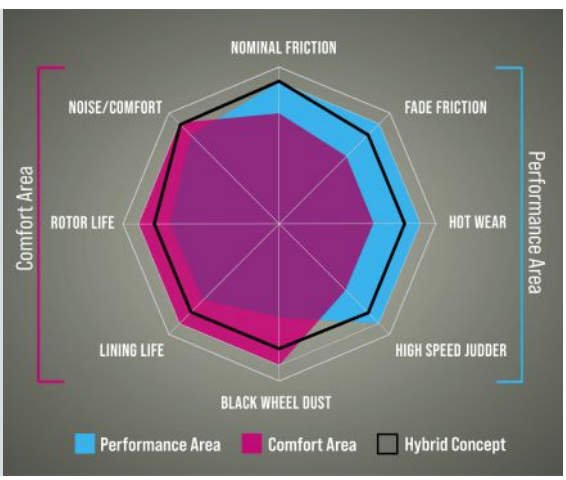
ABOVE RIGHT; Brembo's Enesys (ENErgy Saving sYStem) is designed to diminish residual torque in braking systems

Hybrid friction material

Materials scientists at Tenneco are developing an advanced OE hybrid friction material for brake pads that combines the advantages of low steel (LS) and non-asbestos-organic (NAO) composites.

LS materials offer high-temperature braking performance and can remove disc corrosion, while NAO materials enable good NVH performance and low brake dust contamination. The hybrid composite material blends these qualities, despite their different tribology with regard to adhesion and abrasion. Tenneco says these hybrid pads are particularly suited to e-mobility, in which brakes can be used less frequently than with ICE vehicles, as they can help prevent corrosion and rust. A spider graph of their comfort and performance attributes is shown to the right.

The hybrid friction material is now in series production at Tenneco´s OE braking facility in Chongqing, China, and the company says that several projects are in the testing and evaluation phase in Europe.



Road and track

Many riders of sports bikes and supermotos enjoy track days, and often ride to the circuit. These pads are usually very high quality and effective on public roads, but in track conditions they can fade and suffer increased wear after a few fast laps.

A solution is to change the road pads for racing pads at the circuit , but this is not so easy for weekend enthusiasts, so TRW has developed TRQ, which are racing pads with a compound developed for the race track, but with controllability that has earned them approval for use on public roads. A rider can use the pads on the way to the race track, and once there, after a short braking period, the pads are match-ready for competition use.

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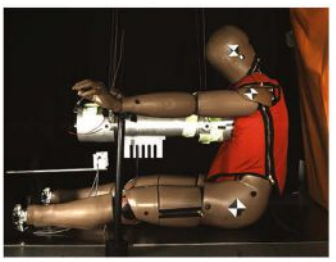


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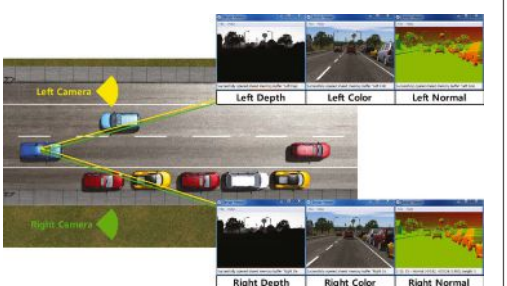

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Braking with artificial intelligence

An exciting development in braking is Sensify, a system that combines current calipers, discs and friction materials with something more high tech: digital technology and artificial intelligence. Its developer, Brembo, says the result is a flexible platform that includes software, predictive algorithms and data management to control the brake system digitally. This is no mere concept, as Brembo expects to launch the technology to the market in early 2024.

For the driver, the engineers aimed for an intuitive, responsive and smooth feel, with control enhanced by independent control of each wheel, enabling precise handling. The system learns the operator's driving style by collecting data during journeys and analysing it, and responds with tweaks to the system responses that improve the driving experience. The optimised braking action on each wheel, combined with the absence of drag between pads and discs, minimises emissions.

Brembo says that Sensify can be integrated into any electric or internal combustion engine vehicle platform, from performance cars to city cars and, potentially, to the latest commercial vehicles.

ABOVE: Brembo has been using the Tesla Model S, among other vehicles, to test and demonstrate its Sensify intelligent braking system

fewer moving parts than an ICE-powered vehicle, which in turn means fewer things to go wrong or to maintain, and an increased lifespan as a result. Such factors could also apply to the braking system which, theoretically, could last the lifespan of the vehicle.

Some observers even argue that in the long-term future, as autonomous mobility becomes a part of everyday life, the fundamental design of braking systems will change due to their function becoming no longer related to safety. Autonomous vehicles will always operate within their safety envelope, making use of connectivity technology that manages traffic flow and will alert the vehicle's autonomous electronics to any difficulties. As a result, brake systems will rarely need to be applied in an emergency situation.

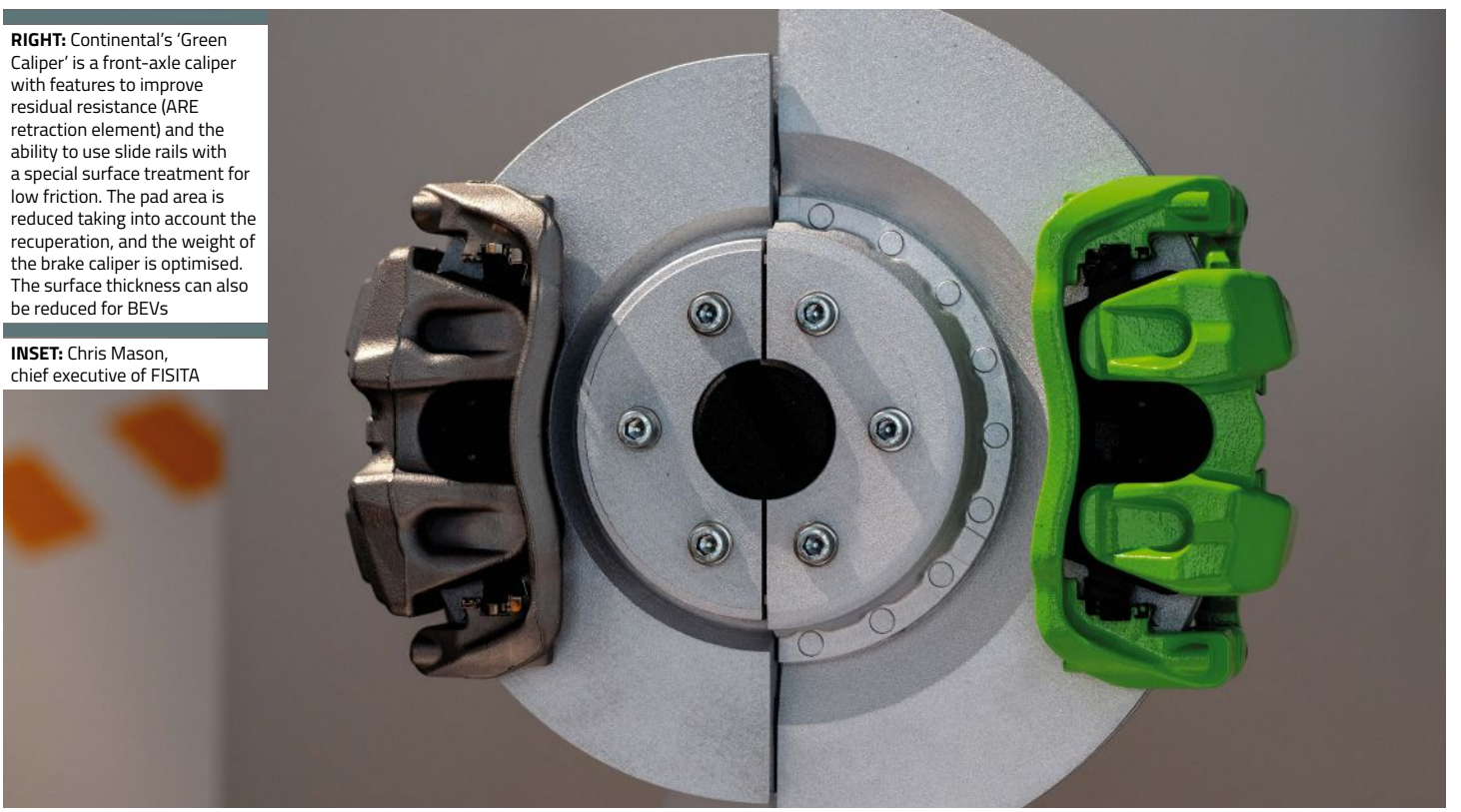
"Brake-by-wire in its full capability will be more expensive, a hybrid solution difficult for some non-volume manufacturers to justify in terms of cost, so advanced traditional braking will continue for some considerable time"

Mason believes there is some way to go before such situations are an everyday normality, though he adds that some elements are already evident in vehicles today in the form of increasing driver-assistance technology.

"[In the future] there will be a layering of driver-assistance facilities that socialise and normalise these things to the consumer, removing the anxieties involved in driving," explains Mason.

However, Mason also argues that cost will be a serious determining factor in the speed of adoption for BbW systems.

"Brake-by-wire in its full capability will be more expensive, a hybrid solution difficult for some non-volume manufacturers to justify in terms of cost, so advanced traditional braking will continue for some considerable time," he says.



RIGHT: Continental's 'Green Caliper' is a front-axle caliper with features to improve residual resistance (ARE retraction element) and the ability to use slide rails with a special surface treatment for low friction. The pad area is reduced taking into account the recuperation, and the weight of the brake caliper is optimised. The surface thickness can also be reduced for BEVs

INSET: Chris Mason, chief executive of FISITA

Dry drum brakes

The next step for EV braking systems could be a move from hydraulics to electric actuation. The introduction of such 'dry' braking systems could begin with the drum brake, a design well suited to electrification as it has a low actuation power requirement than discs, and thus needs only small and lightweight motor-gear-units.

Continental is developing such a dry drum brake system, named the e-DS. This duo-servo brake has sensors that measure the effective brake moment, with a high control rate that ensures that exactly the required force is applied by the compact electric actuator and gear unit inside the dry drum brakes – keeping braking force balanced at both wheels.

QUIET ADVANCES

Mason's view of advances in braking technology is evident in the number of current EV models that still employ traditional braking systems. And on such vehicles a new challenge is emerging, in the area of noise, vibration and harshness (NVH). The small amount of noise made by brakes in operation has traditionally been drowned out by the engine, but in EVs there is no engine noise so braking noise becomes a factor for the consumer.

"The NVH consideration will transcend from traditional cars to the new breed of EVs and be an important part of the electric car driving experience," Mason says. "Away from the emissions agenda, in a brake technology agenda, NVH is the continuing challenge for the brake technology community. The materials that are used, how they are used, how they are applied with each other, is now a co-highest priority for the braking technology community, alongside emissions.

"There is a lot of R&D, resources and finance being put into the continuing evolution of traditional braking systems, which suggests that such systems will be with us for a long period yet, otherwise we would see investment and resource being tailed off. There is much advancement to be had in that area," he adds.

COATINGS DEVELOPMENTS

A significant amount of development of traditional braking systems is being made in the area of coatings for brake discs and calipers, in the process seeking to address the environmental issue of micro particulates. In 2020, braking system manufacturer, Brembo, launched new discs dubbed Greentive, with a mirror-shine green coating formed from tungsten carbide, with the promise of reduced wear, higher corrosion resistance and fewer micro particles.

Similar advantages are claimed for Wecodur, a hard but thin coating applied by laser to brake discs and pads by German technology start-up, HPL Technologies. HPL also believes its technology will make possible the production of lighter-weight brake systems, a particular bonus with EVs, for which every kilo in weight saved potentially adds to the car's range between charges.

On 11 April, ITT Inc. announced its investment in HPL, which intends to combine Wecodur technology with ITT Motion Technologies, brake pads designed for hard-coated brake disks. The investment will help HPL accelerate the industrialisation of laser cladding and grinding machines for brake rotors.

Technological development in traditional systems extends to the smallest elements, such as Brembo's new Enesys brake springs, which by ensuring the brake pads retract fully into the caliper after each use, prevent any extra friction (and potential NVH as well as wear issues) from pads remaining in slight contact with the discs. Brembo is also making such basic moves as producing slimmer, more compact calipers partly made from aluminium – again saving vital weight.

ABOVE LEFT: The Continental e-DS drum brake is based on the Duo Servo principle and provides high brake torques for heavy vehicles on rear axles, or light vehicles on front axles

TOP RIGHT: A layer of coating is applied to Brembo's Greentive disc ring using High-Velocity-Oxy-Fuel (HVOF) technology that reduces environmental impact

RIGHT: The spring in Brembo's Enesys brake makes sure that the brake pads return to their initial position in the caliper once the brake pedal is released

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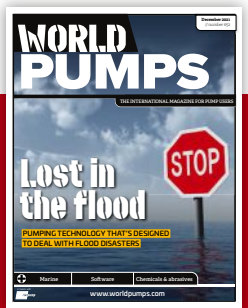

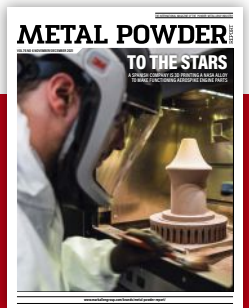

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"Due to the advancement of technology and the mobility transition we've seen in less than 10 years, I would not be surprised if in the next 10 years we see another major advance – one that we are not fully aware of just now – playing its part"

Goodyear is working with TNO to assess the benefits of connected tyres communicating with a vehicle's control system, especially the ABS

Intelligent brake system

Goodyear is collaborating with TNO, a Dutch research organisation, on a demonstration vehicle that will be used to assess the benefits of connected tyres talking to the vehicle's control system, with a specific focus on ABS.

The partners say that when intelligent tyres are connected with a vehicle's ABS system, braking performance can be optimised for the situation and tyre state, while helping with steerability. Previous studies by Goodyear indicate that the integration of these two components can reduce stopping distance loss by about 30%.

The study will look for more meaningful integration, with the aim of optimising braking distance in various tyre operating and road-surface conditions. The companies expect to share the test results this year.

Fast forwarding 30 years or so into the next generation of automobiles, Mason believes that typical braking systems in the mainstream market will still rely on developed versions of traditional technology, with new technology such as fully dry brake-by-wire systems coming more into play the further one moves up the price chain.

He adds a firm caveat, however: "Due to the advancement of technology and the mobility transition we've seen in less than 10 years. I would not be surprised if in the next 10 years we see another major advance – one that we are not fully aware of just now – playing its part."

Mason sees future braking advances as primarily being a continuation of the evolution that has been going on for 100 years in the automotive industry.

"Today the technology is so much better understood that the advancements can be progressed more quickly, brought faster to market.

"I don't see advancement though completely new fundamentals, but rather by developing existing systems against the aspirations to reduce emissions and increase efficiencies," he adds. "There won't be a moment when the old tech stops and new tech starts."