Porsche Engineering

Magazine
ISSUE
1/2018

www.porsche-engineering.com

Dear reader,

Malte Radmann and Dirk Lappe,
Porsche Engineering's Managing Directors

A brief glimpse at the world's major auto shows perfectly illustrates the balancing act automobile manufacturers must master today. Porsche is presenting two cars that could hardly be more different: the new Porsche 911 GT3 RS and the concept car Mission E Cross Turismo. A high-performance sports car alongside an electrically driven cross utility vehicle. A high-revving six-cylinder aspirated engine alongside two permanent magnet synchronous motors. Traditional combustion-engine expertise advanced time and again for decades alongside new, groundbreaking E-Performance. Both have their allure. Both have their place.

This is evident immediately if you contemplate the roughly seven billion people alive today who use around 1.25 billion vehicles—and that's not counting bicycles, trains or airplanes. At present, only a fraction of these are electrically driven. This is the reality of today's road traffic, a reality that will in many regions likely persist throughout the coming decades. In other words, there are many places on Earth where the subject of electro-mobility is on the back burner. Instead, there's far greater interest in vehicles that are robust, fuel-efficient and powerful.

Irrespective, however, of whether we're talking about a classic combustion engine or a cutting-edge electric drive, every component and every system needs to run with absolute reliability. To ensure such, all parts require thorough testing. Testing itself is currently undergoing the exact same dynamic change as the automotive industry: The respective significance of simulation, bench testing, and real-life trials is shifting. This is why we're always devising new test methods and optimizing them again and again—an exciting job and our topic for the dossier of this magazine issue.

Speaking of new, you've likely already noticed that Porsche Engineering Magazine has a new look—and we've revised more than just its appearance. In keeping with the times, we decided to take on the above balancing act between maintaining what's proven and an open mind for what's new: true to ourselves with a magazine by engineers, for engineers. So, we'll still be affording you insights into our high-tech work and projects, but now presented in a more easily comprehensible and more appealing format.

We'll also be setting our sights on what the future will bring and stay keen on exploring the unknown. We're inviting guest writers from all walks of industry to tell us about the challenges they're facing and show what's moving the world beyond the automotive sector.

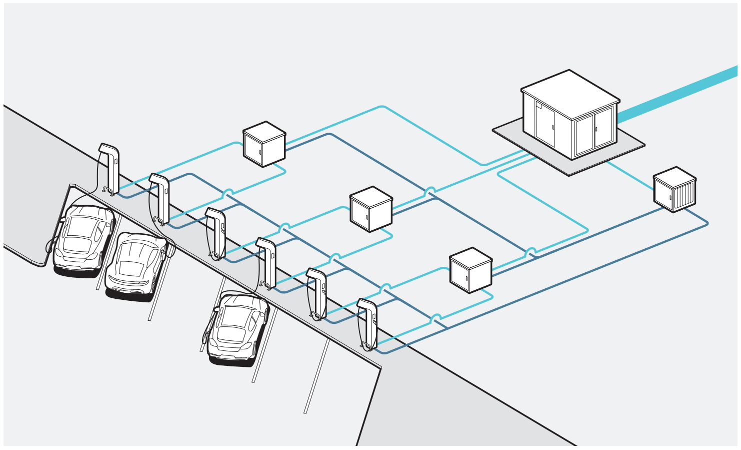
We hope you like our balancing act for the Porsche Engineering Magazine relaunch and hope you enjoy reading it.

Sincerely,
Malte Radmann and Dirk Lappe

Porsche 911 GT3 RS

CO_2 emissions (combined): 291 g/km
Consumption urban: 19.2 l/100 km
Extra-urban: 9.0 l/100 km
Combined: 12.8 l/100 km
Efficiency class: Germany: G
Switzerland: G

ABOUT PORSCHE ENGINEERING — Creating forward-looking solutions was the standard set by Ferdinand Porsche when he started his design office in 1931. In doing so, he laid the foundation for today's Porsche customer developments. We renew our commitment to that example with each new project that we carry out for customers. The variety of services provided by Porsche Engineering ranges from the design of individual components to the planning and execution of complete vehicle developments and extends to industries beyond the automotive sector.




DOSSIER
16–45

Porsche Engineering Magazine

ISSUE 1/2018

Shaping change

Guest author: Prof. Dr. Andreas Knie
Photo: Westend61, David Ausserhofer

Those who leave behind the current state of the art, the certified canon of knowledge, will find it easier to generate innovations and play a role in shaping the future—such, at any rate, is the view of mobility researcher Prof. Dr. Andreas Knie, head of the Science Policy Studies Research Group at the WZB Berlin Social Science Center and Director of Innovation Center for Mobility and Change. An interjection.

The insight that the world is in transition is at least as old as the world itself. Yet the notion surprises us again and again. In September 2015, for example, Uber Technologies Inc., which had been founded in 2009, was valued at just over 54 billion US dollars. This made it more valuable than Volkswagen, the world's second-largest carmaker at the time. The share price would dip back to more reasonable levels within a few days. But the point had been made: Stock markets place a higher value on future potential than the economic strength achieved so far. They reward something that came to be known as the "California way". With Apple, Google, Amazon and Facebook, four of the six most highly valued companies in the world deal directly or indirectly with digital platforms and their economy. And they're all based in California.

The meteoric rise from start-up to global player seems to me to be rooted in the way of thinking. The state of the art in terms of technology is less important when it comes to the California way. A new idea is primarily judged based on whether the people who are supposed to spend money on it actually like it. If that is the case, then it is developed and tested pragmatically without paying much heed to expert opinion. The crucial factor in this model is the attractiveness of a product for the immediate target. That this is all too often associated with the shortcomings of an immature technology is not considered overly important. This is, for good reason, quite different in the professional cultures of companies that have grown over decades. In Germany, a predominant state of technology has developed that continuously evolves in a discursive process involving technical specialists working jointly. The peers—these technical specialists—decide whether a new idea will be pursued or dropped. The result is a system that offers high quality and an astonishing innovation density in all details; at the same time, such a system is also characterized by a high degree of path dependence.

It's time to rethink the predominant professional culture. The objective is to completely reinvent oneself in order to find a comprehensive and sustainable path—not a European or Californian path, but one that is suitable for the whole world.

Is this system still the right answer in an age of digital revolution? This is the absolutely critical question in the face of radical changes. The perfect example of this is the smartphone. The idea originally came from Nokia, and IBM, Ericsson and Blackberry all tried their hands in this development field between 1996 and 2002, but Steve Jobs was the first to recognize its true potential. The iPhone began its victory march in 2007, and today—just ten years later—almost all of us use a smartphone in both our professional and private everyday lives. For the young generation, it has meanwhile become the primary perceptual filter. Everything that is not usable digitally seems quite simply not to be taking place.

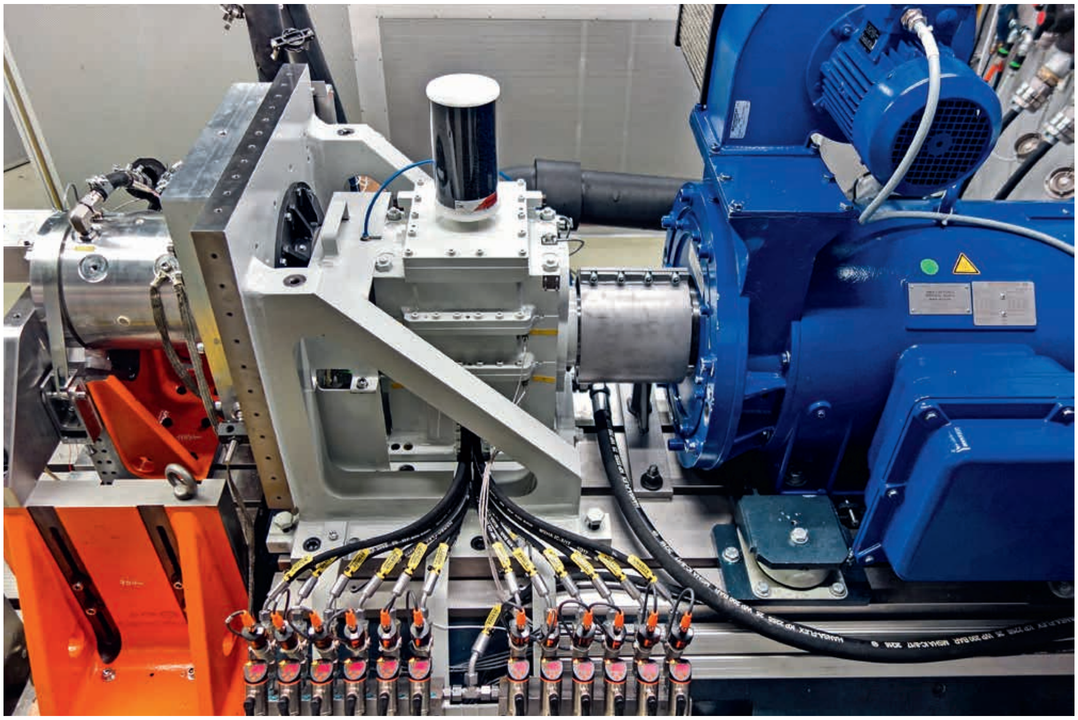
In the past, for example, the selection of a form of transportation was made on the basis of physical properties and of course brand loyalties as well. The contact was more direct, the experience was more tangible and immediate. These worlds of experience also structured the hierarchy of the transport market. But generations Y and Z seem to be setting other priorities. What is decisive for them is no longer the technical configuration of a device and its exclusive quality, but rather one solitary quality: Is this option available right here, right now? Digital platforms are transforming the world of things and services into goods that are available at any time and any place. Whoever organizes these platforms will dominate the world of devices as well. And that is exactly the reason why the stock markets pay such close attention to the developers and operators of these platforms. There's no denying it: The world is changing. Once again.

That's nothing for anyone to be afraid of, because what seems so new to us in the California way is actually long known to us. "Out-of-the-box" thinking, leaving the strictures of communities and established paths behind, granting space to passionate outsiders, turning talents into entrepreneurs—we know all about that in Europe as well. One example is a young man from Bohemia who at the tender age of 17 and against the expressed will of his father brought electricity to the family home, or who as a young adult developed a hybrid drive system. His name: Ferdinand Porsche. If it had been left to society to decide his future, he would have taken over the family tinsmith. But instead he dedicated himself to living out his dream, attending evening courses for electrical engineering at the K.u.K. Staatsgewerbeschule, the state-run trade school, in nearby Reichenberg.

The Europe in which the talented engineer and inventor was born is naturally a different place today, and Reichenberg is now Liberec, yet the challenges are still similar. We have an unprecedented level of economic well-being and a degree of stability that leads to stagnation and complacency. That's why it's time for us to take another look at the predominant professional culture and use the resources that society puts at our disposal more productively as we work together on the projects of the future. To shape this change in an active way, a clear-eyed view of California is in order. After all, what's happening there is in essence a repetition of a history that we already know. With this consciousness, we will be able to reinvent ourselves and embark on an all-encompassing and sustainable path—not a European or Californian way, but a way that's suitable for the entire world.

Prof. Dr. Andreas Knie is a political scientist at the WZB Berlin Social Science Center and a lecturer at TU Berlin. His fields of research include science policy studies, technology research and mobility research. From 2001 to 2016, Andreas Knie was the head of intermodal services and business development for Deutsche Bahn AG (DB AG) and since 2006 has been a member of the executive board of the Innovationszentrum für Mobilität und gesellschaftlichen Wandel GmbH (InnoZ). The partners are DB AG, the German Aerospace Center (DLR) and WZB. On January 1, 2017, he took over as head of the Science Policy Studies research group at WZB.

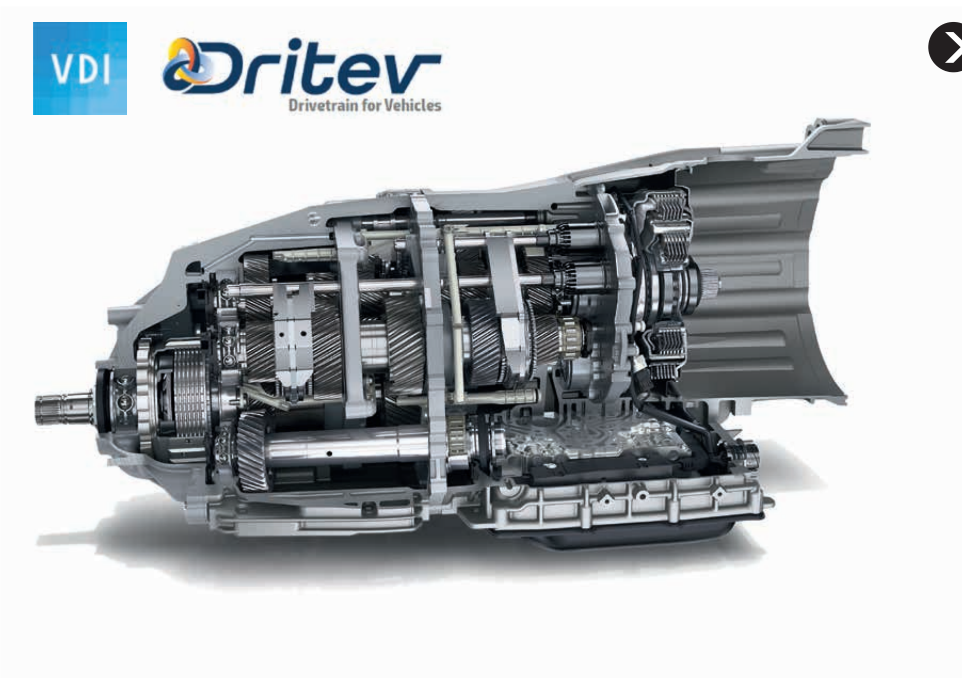
News



DEVELOPMENT

Electric motor testing

Porsche Engineering expands its facilities for testing electric drives. Electric motors can now be tested at speeds up to 25,000 rpm. This accommodates the current trend in the automotive industry toward electric motors with greater power density and higher speeds. Customers benefit from a groundbreaking expansion of trial and application options for electric motors and frequency converters.



EVENT

VDI show Dritev

Dritev—Drivetrain, Transmission and Electrification in Vehicles. The seminal congress is one of the world's largest networking platforms for researchers, engineers, and manufacturers of drive systems and vehicles. The congress is supported by a trade show featuring more than 100 exhibitors. Porsche Engineering will also be maintaining a stand with experts at the still new event.

June 27–28, 2018
World Conference Center,
Bonn, Germany

70 1948 2018 PORSCHE

ANNIVERSARY

70 years of Porsche sportscars

June 8, 1948, the Porsche "No. 1" Roadster, in-house designator 356, obtained approval for use in road traffic with the license plate number K45-286—the first step in the life of a world-famous sportscar producer. Porsche will be celebrating the anniversary with the "Sportscar Together Day" from June 9–10, 2018, and a dedicated exhibition at the Porsche Museum in Zuffenhausen starting June 9, 2018.

THE NEXT GENERATION

Master degree course in Cluj

The Technical University of Cluj-Napoca (TUCN) and Porsche Engineering Romania hosted a joint get-together to celebrate the first master degree course in Advanced Techniques in Automotive Engineering (ATAE). Twenty-five young students can now prepare for the future during the two-year degree course. Marius Mihailovici, General Manager of Porsche Engineering Romania: "The new Master of Science course is designed to provide students with as much practical experience as possible of the challenges faced in automobile development by instructing them in the expertise of our engineers."

A deeper connection

Text: Johannes Winterhagen
Photos: Sven Cichowicz, Illustration: d3

For decades, scientists have been fascinated by the topic of artificial intelligence. Many systems created under this epithet have been artificial for a long time, but intelligence has not been a property they widely possessed. Over the last seven years, however, this has changed rapidly: With deep neural networks, developers now have a powerful tool at their disposal. But how does deep machine learning work? How can it be put to use for future vehicle generations? And what does Porsche Engineering have to do with it? Read on to find out.

In July 1956, creation of the first artificial Man seemed imminent. A group of computer scientists and mathematicians at the renowned Dartmouth College in New Hampshire in the USA had sent out the call to join an ambitious research project—the *Dartmouth Summer Research Project on Artificial Intelligence*. In their enthusiasm, the project's founders believed to have speaking machines, networks modeled on the human mind, self-optimizing computers and even machine creativity at their very fingertips. But although a busy summer's month produced little more than sheaves of writing and big ideas, the utopian scientists did coin the term *artificial intelligence* (or AI for short) and create an entirely new field of research that would from then on keep the whole world holding its breath.

Artificial intelligence: tricky to pin down

A good sixty years later, one thing's for sure: What is referred to as true, or general, artificial intelligence—that is, AI that comprehensively copies or even exceeds human intelligence—is a utopian dream even today. No technological system in the foreseeable future will be capable of passing the Turing test (see info box). 'Weak' AI systems, which are currently the primary object of research, are not even intended to pass the Turing test. Instead, these systems' design pursues autonomous processing of problems within defined boundaries or responding to input questions. Weak AI algorithms are becoming better and better at overcoming concrete problems of application, for example the solution of complex logical or mathematical expressions. They can also act as opponents in a game of chess, checkers or Go. They excel at analyzing large volumes of text or data and form the core element in internet search engines. Embedded in myriad smartphone apps, artificial intelligence is already our constant

The Turing Test: Conceived by the mathematics genius Alan Turing (1912—1954), the test is intended to allow a decision on whether a machine possesses a level of intelligence comparable to a human's. To conduct the test, a human and the tested machine are each put in a separate, locked room. From there, they both communicate with the tester, who is located in a third room with no visual contact with the others. If the tester is unable to determine whether they are communicating with the other person or with the machine, the machine is deemed to have passed the Turing test.

Artificial intelligence at the wheel: Porsche trial vehicles incorporate high-end computers that are capable of handling the driving. Test drives by trained drivers and programmers prove that level 4 autonomous driving is already possible today.

USA

The Massachusetts Institute of Technology (MIT), the California Institute of Technology (CalTech) and Stanford University are considered forerunners in AI research.

DFKI

The German Research Center for Artificial Intelligence is the world's largest research institute for AI.

Cyber Valley

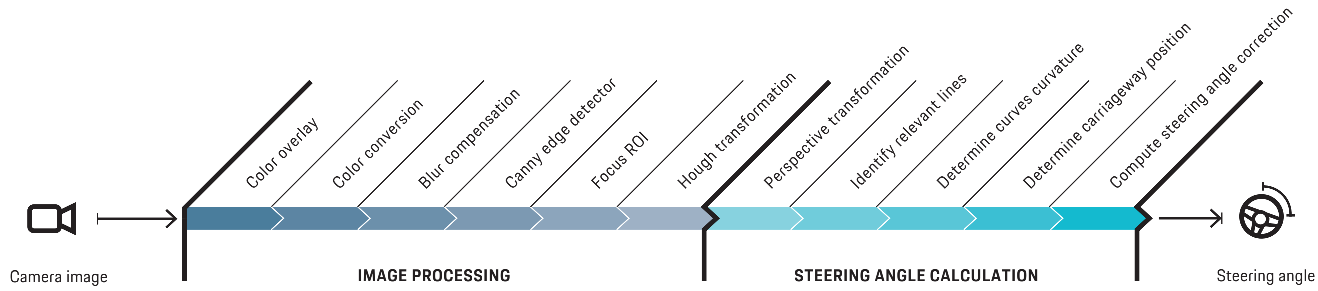
Cyber Valley, founded 2016 in southern Germany, provides fertile ground for AI research.

companion—we users are frequently barely aware that we're carrying AI around with us in our pockets. When we speak to "Alexa" or "Siri," our words and phrases are analyzed by AI algorithms. As the founder of the Dartmouth Conference John McCarthy himself already drily remarked on the fate of AI applications: "As soon as it works, no-one calls it AI anymore."

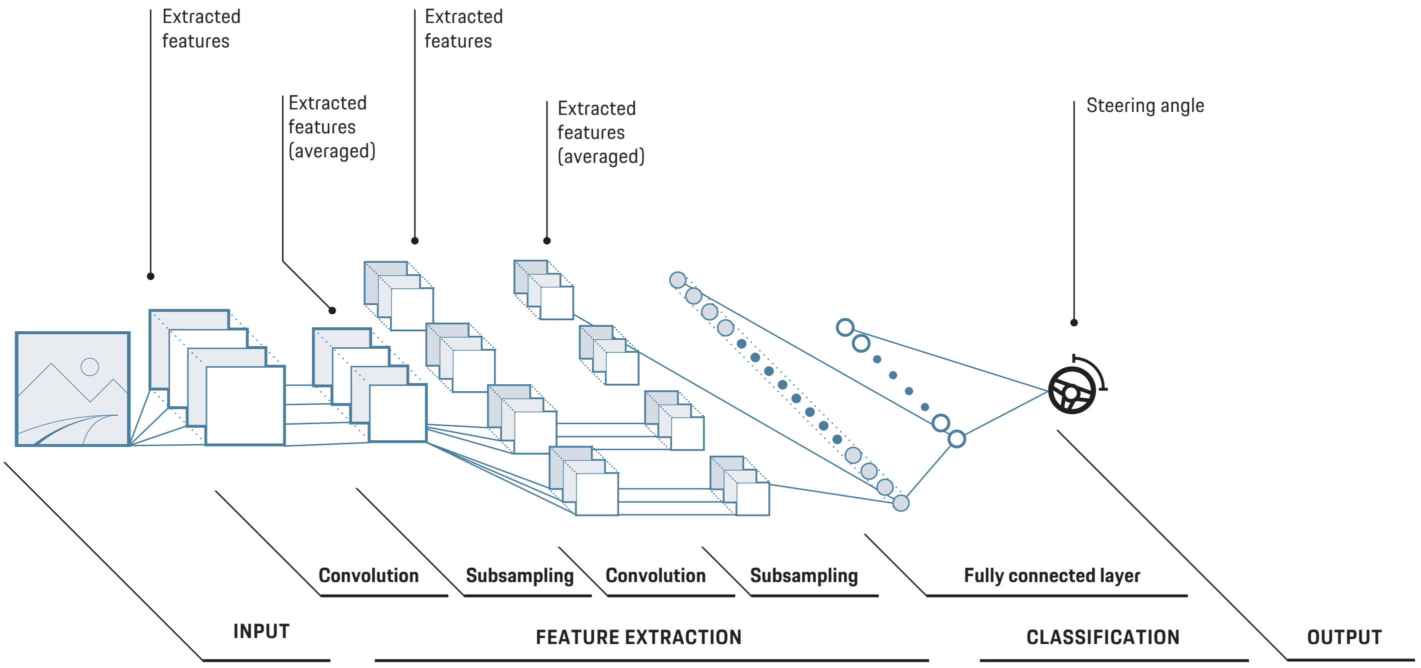
As interconnected as a brain

The first artificial neural networks were already devised in the early 1950s. These networks are the key to artificial intelligence's success. In such a network, the separate computation operations are not rigid, binary computing that allows only two options: 1 or 0, on or off. Instead, they are modeled on biological nervous systems. Nervous systems operate based on threshold values and can accommodate a multitude of values between 1 and 0; a seemingly infinite number of nerve cells are dynamically interconnected by growing, mutable links. The human brain learns by constantly reassessing these links' weighting. Pathways used frequently are reinforced, rarely used links allowed to wither. Of course, artificial neural networks run on conventional computers—ultimately, they too operate based on ones and zeros. But within this system, the complex algorithm's operating principle and threshold logic reflect their biological counterparts.

Artificial, interlinked neurons are fed input values and pass the data on to neurons at a downstream level. At the chain's end, a level of output neurons supplies a result value. The variable weighting of the separate connections lends the network a remarkable property: an ability to learn. Today, these networks possess more and more levels; they are more complex, more greatly nested—they are deeper. Deep neural networks in some cases comprise more than one hundred of these successive program levels. Being learning networks, they usually keep on taking corrective feedback into account until they are able to produce the ideal solution to a problem—for example in image recognition: During training, also referred to as 'deep learning', the system devours thousands upon thousands of photographs until it is capable of making statements about previously unseen images. It performs a feat of knowledge application: It sees a cat as a cat; it calls an apple an apple, even when the apple is semi-obscured by leaves; it recognizes traffic signs, deer, humans. Highly reliable recognition not only allows robot taxis to follow traffic rules but even now also helps surgeons identify tumors. Computer resonance imaging scans are more and more often compared with medical image databases in a fully automatic process.



1 **Current method:** The processes are executed along a linear sequence from input to output.



2 **Deep learning in a convolutional neural network:** Sequentially applied filters modify the image to successively improve resolution of the sought features with every step.

Convolution:
Links each minute image section to a single neuron. This produces multiple layers of feature maps, all of which have received identical input. However, by applying a different weighting, each layer extracts different features (image content).

Subsampling:
Subsampling (also referred to as pooling) rejects extraneous information by keeping only the feature of the neuron with the greatest activity for the next calculation step. Convolutions and subsampling can be continued through any number of iterations.

Fully connected layer:
Forms the network into a whole, merges the results of the last feature map, and outputs the data in a format that facilitates interpretation.

“Deep neural networks today achieve very high success rates.”

Dr. Christian Koelen, Porsche Engineering

For a long time, deep neural networks were largely disregarded by AI research. The chaotic nature of their growth was unable to keep up with the speed of the classic deterministic algorithms. But in the noughties of the new millennium, computing power slowly became sufficient to exploit the full potential of deep networks. Geoffrey Hinton from the University of Toronto in Canada had long suffered mild ridicule for his self-teaching approach. In 2020, however, he won the *ImageNet Challenge*, a competition in which AI systems compete to correctly interpret hundreds of thousands of images.

Diverse applications

Deep neural networks shine in any field that needs to analyze complex patterns: They recognize, interpret and translate languages, analyze video sequences or predict stock price developments. They are the core element of voice assistants such as those used by Amazon or Apple. With an extensive, but targeted training, they can learn to play computer games or even beat human Grand Masters at the highly complex game of Go. When combined with other types of networks or with robotics, the capacities of deep networks can be vastly expanded: For a long time now, artificial soccer players have played each other in the annual RoboCup championship. They react entirely autonomously to their opponents, interact with teammates and occasionally even manage to score a goal. At this year’s RoboCup in Nagoya in Japan, the smartest robots were given the opportunity to compete autonomously in other disciplines, too: For example in the Logistics League or the *@work* industrial robot category, rescuing accident victims in disaster scenarios in the Rescue Robot League or as electronic butlers in the *RoboCup@home* competition.

Test drive: Assistance systems, for example Lane Keep Assist, already benefit from deep learning today.

1997
The super computer "Deep Blue" beats World Chess Champion Garry Kasparov.

2011
The IBM computer "Watson" wins a US TV quiz show against two human contestants.

2016
Google's machine learning system "AlphaGo" beats the Go world champion.

2060
is when some credible scientists believe AI will exceed human intelligence.

The progress made in the field of artificial intelligence will drive radical changes in the mobility sector over the coming years, as the massive complexity of road traffic, particularly in urban population centers, will push classic algorithms to their limits when developing highly automated or even autonomous vehicles. Dr Christian Koelen, project leader at Porsche Engineering, explains: "Covering all imaginable parameter variations using classic algorithms would take a very long time and incur high expenses for programming and tests." For object classification to reliably detect other traffic, such as pedestrians, Porsche Engineering has chosen to pursue the method of deep learning. "Deep neural networks today achieve very high success rates," Koelen confirms.

"We're combining a classic Porsche virtue—transverse dynamics—with artificial intelligence, which is a new core competence for us."

Johann Haselberger,
Porsche Engineering

Promising practical tests

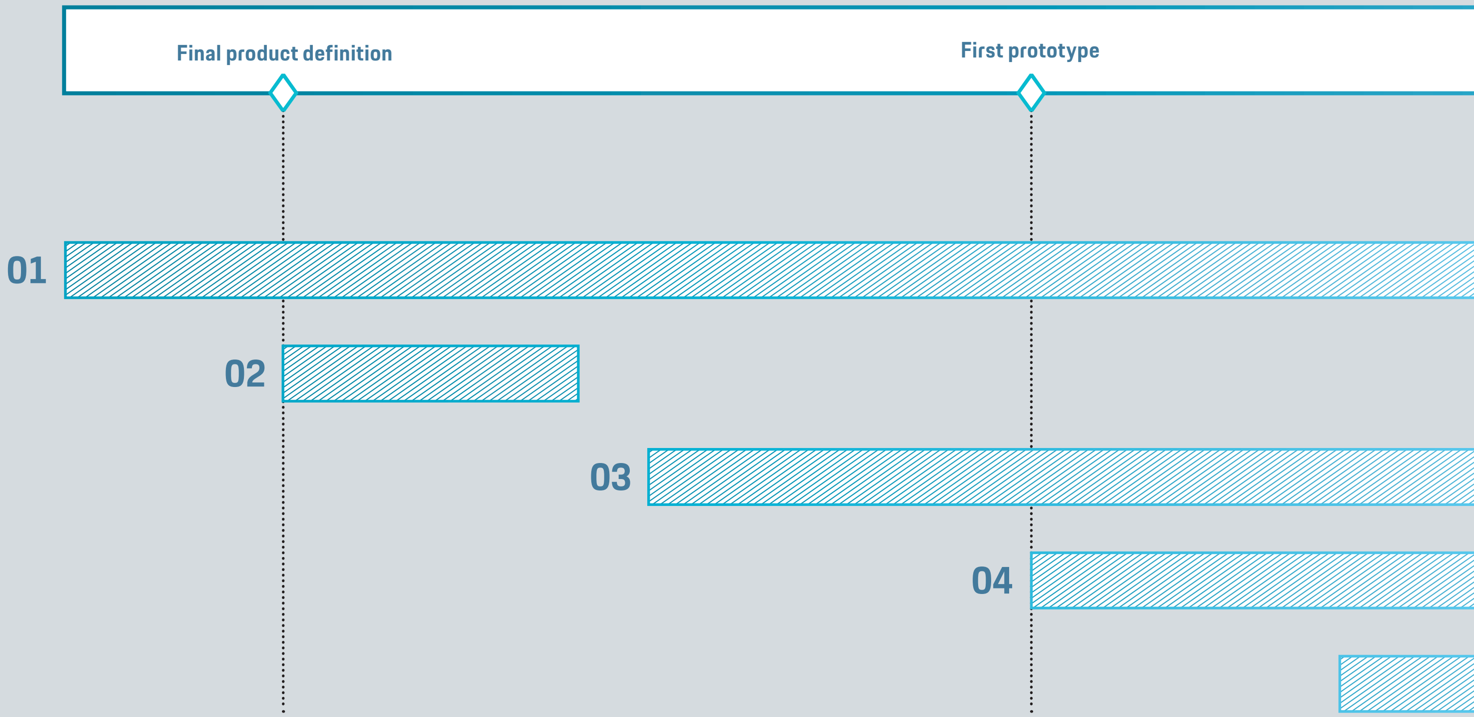
But artificial intelligence is not only of use in recognizing your surroundings during automated driving. Assistance systems like Lane Keep Assist, for example, can also benefit from deep learning. Porsche Engineering's Johann Haselberger has completed a feasibility study that proves it. The issue is no small matter. After all, assistance systems of this kind take control of the steering while driving. For the neural network to make the right decision within fractions of a second, it first needs to be trained. Professional drivers completed long test drives in the area around Stuttgart in a trial vehicle equipped with a high-performance computer and two new video sensors. While driving, the human driver's steering motions were continuously correlated to the video recordings of the road ahead. Roughly half of the time, the car was driven on the motorway. The other half took place on country roads and under dynamic driving.

After several weeks, the system was put to the test: The neural network was allowed to drive by itself. "Both the computer simulation and the real-life tests on the road provided pretty good initial results," Haselberger says. But they also showed that the current development status still has a few shortcomings. The robustness of the neural-network-based controller depends on the volume of input training data, and control quality depends heavily on the training material used. Special circumstances that the controller has not yet "seen" in training—say road work with special markings—are in reality hardly manageable. Nonetheless, dangerous situations are precluded: The classic controller always remains active in the background. Were the neural networks to deliver nonsensical values, they would be instantly overruled. This kind of combination of machine learning and classic deterministic algorithm is referred to as a hybrid system. Many experts expect these hybrid systems to become commonplace in the automotive industry in the near future.

When this article was being written, road testing had not been fully completed. But Koelen holds to his conviction: "This technology has great potential for providing drivers with even better assistance. We can imagine using it in series production by early next year." There remains a fair bit of work to do until then. In a standard-production car, drivers should still be able to decide whether they would prefer to corner in a sporty and dynamic or more conservative style. And the assistance system also needs to react correctly when drivers choose to change their driving style mid-corner. Haselberger is looking forward to the work ahead: "We're combining a classic Porsche virtue—transverse dynamics—with artificial intelligence, which is a new core competence for us. It's really exciting." Who would argue with that?

Further reading on the subject

- **Ulrich Eberl:** *Smarte Maschinen, Wie Künstliche Intelligenz unser Leben verändert*, Carl Hanser Verlag, June 2016
- **Christoph Drösser:** *Total berechenbar?: Wenn Algorithmen für uns entscheiden Taschenbuch*, Carl Hanser Verlag, March 2016
- **Yoshua Bengio, Aaron Courville, Ian Goodfellow:** *Deep Learning (Adaptive Computation and Machine Learning)*, published by The MIT Press, January 2017
- **Tariq Rashid:** *Make Your Own Neural Network*, CreateSpace Independent Publishing Platform, March 2016



Testing the future

Testing at every stage of development—the be-all and end-all of targeted engineering. We present five dossier topics covering our work methods, our philosophy and our innovations in this essential field. The bars above show when the aspects below come into their own during product creation: from the first software test to the final test drive.

DOSSIER

TESTING

01 Software testing

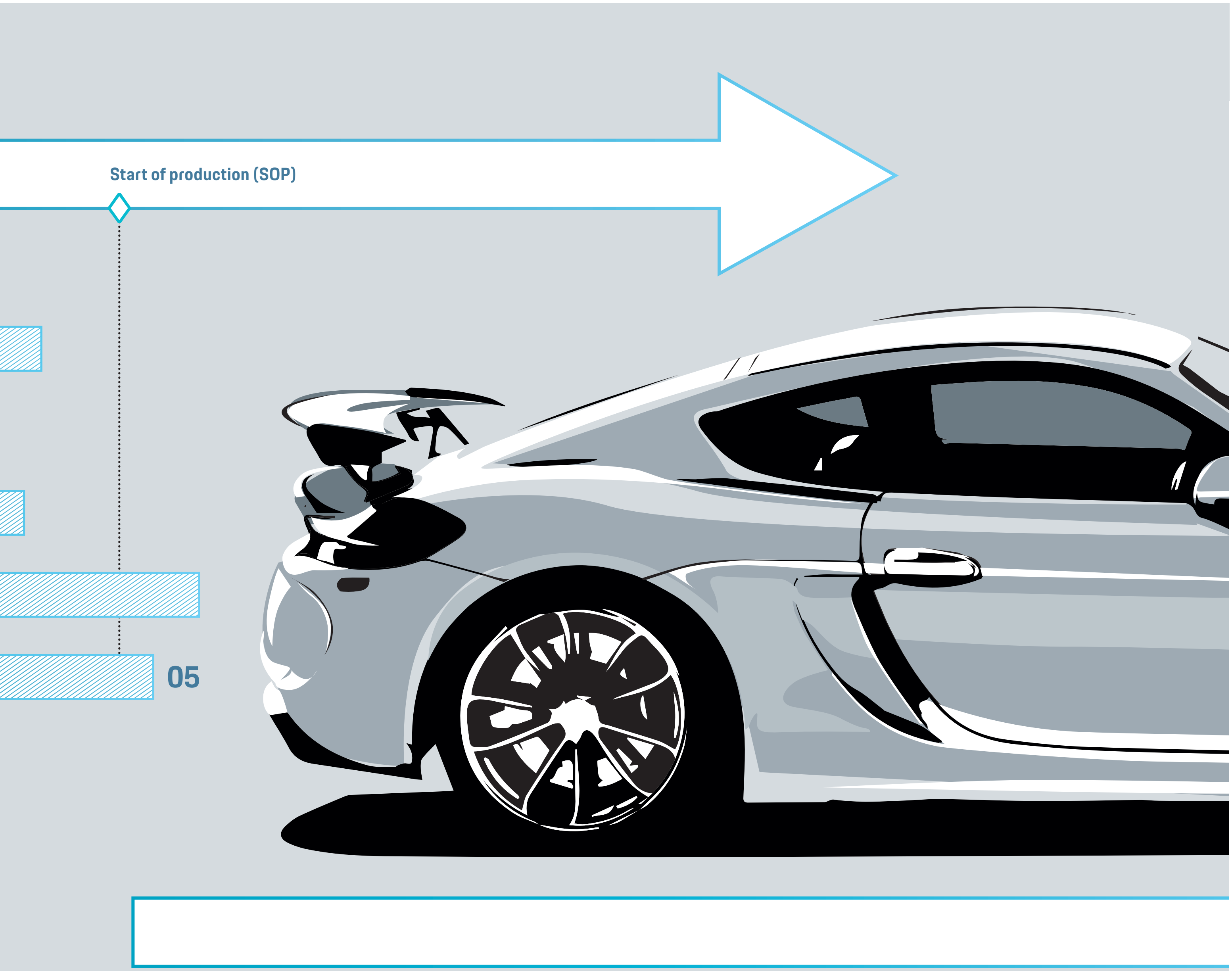
Electronics in cars are becoming ever more complex. Intense control unit testing on the HiL test rig ensures reliable operation.

→ p. 20

02 BMS Mini-HiL

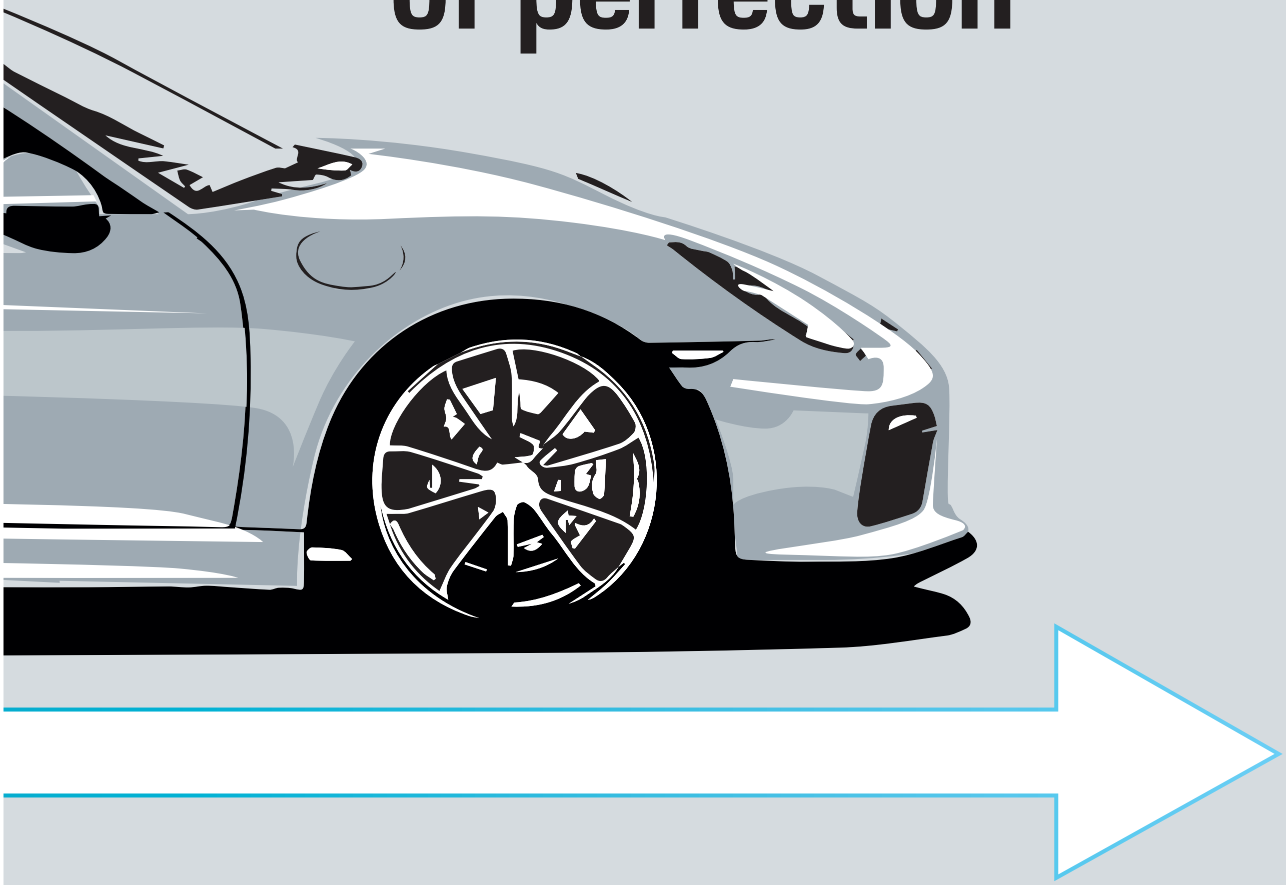
Porsche Engineering's own miniature-format test rig is used to test battery management systems (BMS) in electric drives.

→ p. 26


Start of production (SOP)
05

TESTING

The three stages of perfection



Text: Hans Schilder

When developing a vehicle, testing has a major part to play. And all the while, testing itself undergoes the same dynamic change as the automotive industry as a whole. Ever more complex systems require absolutely reliable testing in ever shorter time. One thing transpires: Simulation, bench trials and real-life testing will always remain a triad. But respective significance shifts. For this reason, Porsche Engineering develops new test methods and optimizes them time and again. Because testing tomorrow's mobility today makes for an exciting challenge—and a great topic for our dossier.

Testing at Porsche Engineering has become a field of growing significance. Every time a project's conceptual phase completes and all calculations are finished, three stages of testing follow to mature an idea to an optimum result. Every development at Porsche Engineering undergoes comprehensive testing—although the subject matter differs every time, from the minutest component to every complete vehicle, everything is put through a formally identical procedure:

- Computer model simulation
- Intense component trials on test benches
- Test drives with real vehicles on test tracks and real roads

Simulation—quick, cost-efficient, reproducible

Today, vehicle development and the corresponding testing would be impossible without using digital tools. The progressive complexity and growing number of variants result in an exponentially increasing testing volume that can only be managed using smart testing methods.

In computer simulations, any component can be examined under the most varied of load scenarios. This way, engineers can optimize a vehicle's components both in terms of modelling and function—long before any of them actually get built. Of course, this requires the simulation models to accurately reflect reality. Upon completion of the simulation stage, developers expect a product's features to operate correctly to at least 85%.

Test bench—components at breaking strain

At the very beginning of the bench testing stage, one of Porsche Engineering's developments is afforded a key role: The Mini-HiL (see page 26). This miniaturized hardware-in-the-loop tool opens up completely new possibilities for engineers. Control units and battery management systems in particular can be tested in simulation and emulation environments for longevity and proneness to faults at a very early stage. This makes the mini-HiL a bridge connecting simulation and actual components.

However, testing at this miniaturized scale cannot supply useful results without more comprehensive function and software testing. How hardware-in-the-loop testing works in detail and which performance indicators play a role here is the topic of a further dossier article (see page 20). During this stage, hardware and software come into contact with more and more actual components. Using the results of the simulations, specialists at Porsche Engineering produce sample components for bench testing. To do so, they fall back upon a combination of craftsmanship and high-tech. Besides precision, customers always expect time and costs to be saved. The repertoire Porsche Engineering has at its disposal to reconcile these conflicting goals includes production techniques such as additive manufacturing, rapid prototyping and rapid tooling. After the separate components, combined systems are put to the test.

Powertrains and their components provide a good example of components tested to their limits and beyond with the aim of examining their long-term strength under reproducible, extreme conditions (see page 30). For the intense trials, experts use a multitude of cutting-edge test benches, including system test benches for engines, axles, chassis, powertrains and brakes as well as vibration test rigs for static and dynamic component testing.

Real-life tests—professionals driving mules and prototypes

Practice has made it evident that simulations and bench tests have limits. Vibration and resonance within the vehicle as a whole, unexpected effects through interaction of separate aerodynamic components—all of these entail scenarios only encountered in the finished vehicle. To test a vehicle under real-life conditions and to ensure it will survive actual use, its prototype is subjected to endurance trials under extreme conditions. For safe testing all year round, Porsche Engineering uses its Nardò Technical Center. The test track's conditions are outstanding (see page 36). Tweaks made to the legendary circuit, advanced workshops, and state-of-the-art data networks and safety facilities ensure that Nardò more than meets the stringent requirements of real-life testing. At times, the test drivers in Apulia will even be famous, such as Mark Webber. We spoke to the former Formula 1 and WEC driver about what makes a good test driver (see page 44).

Simulation, bench test, real-life testing—even with shifting significance and changing requirements, every Porsche Engineering development will always need to pass through these three stages. Porsche Engineering strives to create best quality in the shortest of time. This dossier shows that this is done with a constantly growing team working on all stages of state-of-the-art testing.

TESTING

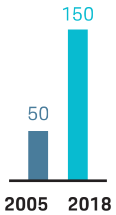
The key to effective testing

Text: Dr. Muhammed Türker and Heiko Junker
Photos: Markus Bolsinger

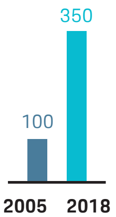
With the intensive use of hardware-in-the-loop test benches for testing control units, Porsche Engineering is pursuing an ambitious goal: shortening the development time for new cars while maintaining the highest standards of quality for all components.

The electronics in cars are becoming ever more complex, as evidenced by the rising number of sensors and actuators. In 2005, there were roughly 50 of them in the Porsche 997. In the current Porsche models, the total is in the neighborhood of 150. At the same time, the number of pins in the engine control devices has risen more than threefold from roughly 100 to about 350. A similar development has been seen with the control units for the transmission and suspension.

These electronic control units continuously interpret sensor measurements and prompt actuators to execute corrective measures in case of deviations from the stored target values (see figure 1). This makes them indispensable for the correct functioning of numerous vehicle functions, and their hardware and software must operate flawlessly under all circumstances. This exacting standard translates into intensive testing.



Number of sensors and actuators on a Porsche engine control unit



Number of pins in an engine control unit from Porsche

Virtual environment

The principle can be reduced to a simple formula: The more complex the vehicle electronics, the more extensive the tests with which the engineers validate the control units on HiL (hardware-in-the-loop) test benches, which are used at Porsche Engineering to test a wide range of vehicle components, such as control units for battery management systems (see page 26). For testing purposes, HiL test benches simulate the respective vehicle environment. The real electronic control units are connected via their inputs and outputs. Thanks to the virtual environment, changes and adjustments to the driver and environmental factors can be implemented rapidly. The tests are also reproducible and can be repeated for various software versions. Moreover, the resource “HiL test bench” is not nearly as scarce as the resource “actual vehicle.”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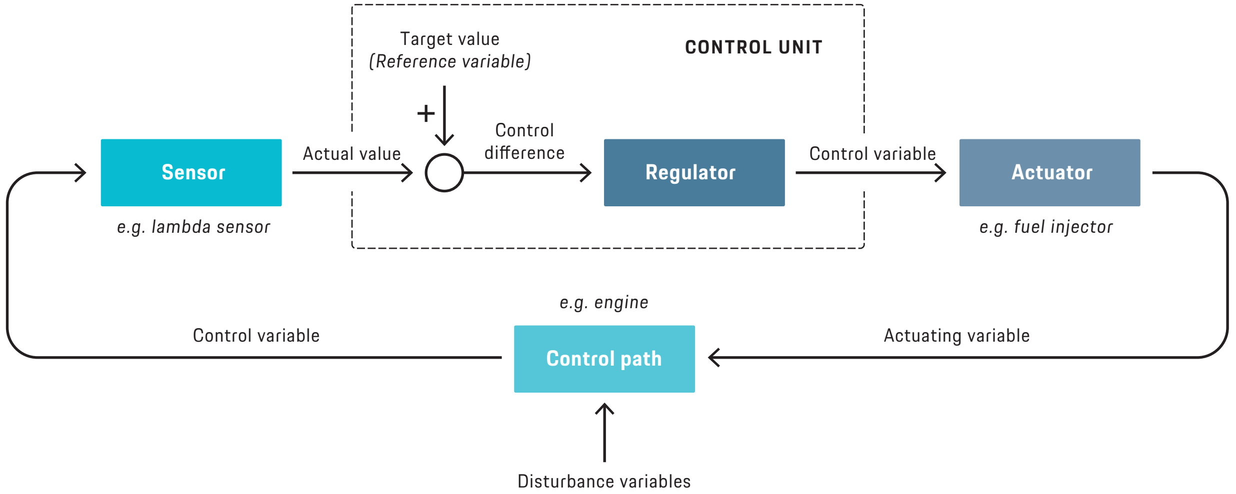
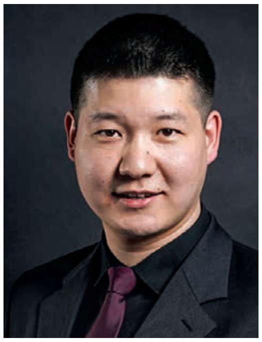


1 **Measurement and control:** Sensors supply the input for the electronic control unit, which then compares the measured actual values with target values. If the actual values deviate from the target values, the control unit initiates corrections via actuators.



Dr. Muhammed Türker
Technical project engineer in the field of functional validation on the hardware-in-the-loop test bench for transmission control units

The HiL testing environment enables numerous tests of the control unit:

- **Interface tests:** These tests check the scaling between the input variables to the control unit and the internal variables in the control unit.
- **Diagnosis tests:** These tests consist of signal manipulations on the BUS level or manipulations on the electrical level, as well as communication tests.
- **Function tests:** These tests are used to check the reaction to the function software to manipulations of various input variables.
- **Stress tests:** These tests repeat a process frequently within a defined time window or run in long-term operation.
- **Extreme tests:** Extreme situations such as the application of drive torque during an active parking lock can be simulated with test procedures without running the risk of causing irreversible damage to the hardware.

First individually, then together

As a rule, engineers first test control units individually on a component HiL test bench. To do so, they connect the control unit to a test bench as the only real component. If the validation is successful, they check the function software as a composite unit. To do this, they connect several real interacting control units to an HiL test bench.

The not actually available but required control units in the test network form what is known as a restbus simulation both in the component HiL test bench and the composite HiL test bench. The restbus simulation is based on a communication matrix (C-matrix). It includes information about signals sent or received by individual control units, such as cycle time and default, error or initial values.

Creating a model for simulations

In addition to restbus simulation, the mapping of the real world also includes a simulation of the vehicle environment, including the driver, environment and vehicle. The interface from the simulation model to the control unit, the I/O connection, encompasses the electrical measurement technology and signal generators. One possible development environment for simulations is “Matlab Simulink” (Mathworks), which Porsche Engineering uses on the suspension, engine and transmission HiL. The model created with Matlab Simulink is compiled and loaded as an executable file on the real-time computer in the HiL simulator. The signals are transmitted to the control unit (routing) via I/O cards, signal conditioning and failure insertion unit (FIU). The I/O cards are capable of processing digital and analog signals.

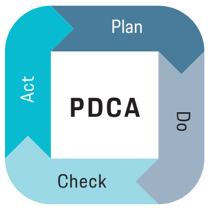
The FIU makes it possible to simulate electrical faults such as short circuits, short circuit to positive or power failure. Tools such as CANape, INCA, DiagRA and ControlDeskNG are used to manipulate and read the signals.

Test processes create trust in the software

A testing strategy refined over years now makes it possible to filter out the maximum number of errors with a finite number of tests. Only when complete trust in a new software version has been achieved, do developers move on to the next step. The basis for every development step is the specifications. The functional scopes demanded there define the test specifications. These are entered in the DOORS (Dynamic Object Oriented Requirements System) software, for example, and managed in a structured manner. Using DOORS, individual test cases can be assigned to various projects using attributes. For example, a particular test case can be carried out in multiple test environments, for various models and control units. This central management prevents unnecessary identical test cases and minimizes the amount of maintenance required. The test process is incorporated in a PDCA cycle (plan—do—check—act) (see figure 2).

To ensure that the tests are reproducible at all times, the test results are summarized via the group tool EXAM (Extended Automation Method) in the form of a report. This report contains the preliminary conditions, the individual test steps and the observed results in a clear presentation. A test case is rated as "OK" if the expected result matches the observed results. If they do not line up, a test case can be classified as "open." Open test cases could be due, for instance, to incidents that emerged after some delay and need to be clarified with the responsible parties.

2



P
Plan:
The specifications describe the requirements.

D
Do:
The requirements (later also changes) are implemented in software.

C
Check:
Tests are conducted in the HiL.

A
Act:
The test results are evaluated and required changes determined.

Repetition at regular intervals

After each test case, function extensions and/or fault corrections lead to a new program or data update. This new state, in turn, is subjected to a test run. Function extensions and fault corrections occur at regular intervals. The goal is to achieve a difference between the expected behavior and the observed behavior approaching zero.

Along with the periodic software/data updates, the followings steps recur:

- Update of the test specifications in the test cases in DOORS
- Synchronization of the test cases in EXAM
- Flashing the new software state to the control unit
- If necessary: Modification of the restbus simulation
- If necessary: Modification of the simulation model
- Test execution
- Communication of the test results to the system owners
- Discussion of test results

Automatic tests save time and money

With ever-more-complex systems, testing activity has ballooned substantially in recent years. In particular, a multitude of tests must be continually adapted to new requirements. This, in turn, creates a need for shorter development cycles. If tests are manually implemented to this purpose, the susceptibility to errors rises accordingly. The logical consequence is therefore to automate testing to a greater extent.

An automated test procedure also offers the advantage of yielding test results rapidly. This makes it possible to identify errors in a quick and timely manner and, thus, avoid unnecessary costs.

The interface from the simulation model to the control unit: The I/O connection encompasses the electrical measurement technology and signal generators.

Heiko Junker
Senior Manager
Electrics/Electronics in the drivetrain field

Other time savings are produced through the customary practice of conducting test preparations during the day and running the tests overnight or over the weekend. The follow-up work takes place on the following day—activities such as individual manual tests or erratic verification of test results. In this way, automated testing increases efficiency and, thanks to rapid implementation, offers high test depth, with a large number of test cases per time unit.

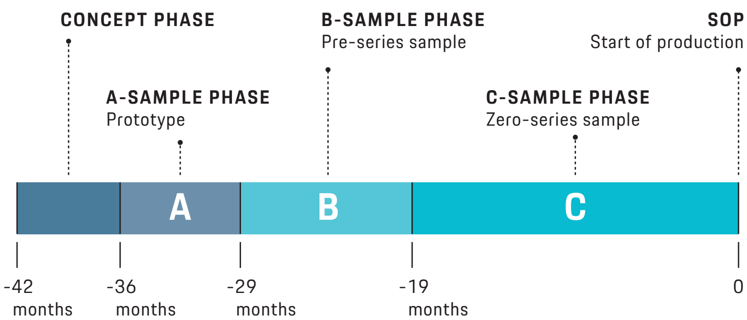
Automated tests are conducted with the aid of EXAM. The test cases specified in DOORS are synchronized with EXAM and are available to the tester in the form of test cases with the associated test description.

Automated testing therefore opens up a variety of options:

- A tester manually implements the test cases using the test description; the test then runs automatically.
- Automated test implementation from Excel tables and automated test execution—suitable for simple test structures.
- Generic test implementation and automated test execution—an extended option with unambiguous and well-structured test cases.

Automated testing enhances efficiency while offering high test depth.

3 **Three-and-a-half years:** A product in development goes through a concept phase and three sample phases before the start of production.



HiL in the product creation process

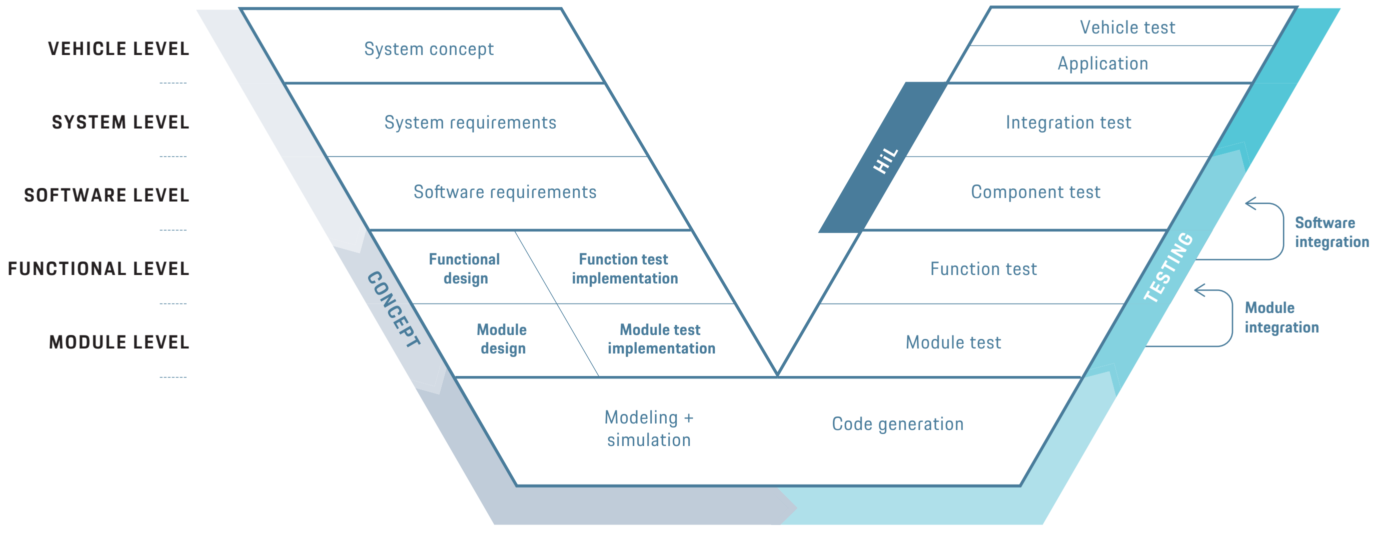
Porsche Engineering incorporates HiL test benches at an early stage of the product development process and continuously accompanies the four component sample phases (see figure 3) in the product creation process with extensive tests through the start of production (SOP):

In roughly the 42nd month before SOP, preparations for the HiL test bench structures begin. Roughly six months later, the A-sample phase begins. In this phase the engineers check the basic functions and decide on the basis of these initial test results which steps are necessary for the further course of development. Among other things, the work in this phase includes the commissioning of the first program/data versions, all actuators and sensors, the bus systems and the interfaces between the software and hardware.

The B-sample phase is to check the new function scopes and encompasses final optimizations with regard to series development. In the context of this phase, fault simulations and interface tests, among other elements, are tested.

In the C-sample phase, extended function scopes are checked in their variant forms and a technical approval is issued for series status. This phase includes function tests, error replacement measures, virtual test drives, analysis of difficult-to-reproduce

4 **Concept and testing phases in the V model:** The individual steps go through the same levels—the test steps are conducted in reverse order, however. The tests on the HiL encompass component and integration tests.



faults and endurance tests and a variety of other tests in its comprehensive testing program.

Testing activities in the area of the engine, suspension and transmission HiL are primarily located on the software and system level in the V model (see figure 4), while activities in the application area take place on the vehicle level. Thus, the HiL technology accompanies the entire product creation process in optimal fashion and enables efficient design of this process.

Outlook

Currently a test description can be automatically interpreted and the test conducted in an automated process. Moreover, some individual tests can be created automatically from the impact matrix, obviating the need for an explicit test description.

In the future, test specifications are to be created using existing data such as impact matrices and specifications, automatically created and converted into lines of code. However, this is predicated in part on further necessary standardization of digitally readable specifications. Porsche Engineering is hard at work on making it possible.

Another focal point for the future will be automated HiL test bench configurations of the control unit, sensor and actuator specifications, including cable harness definition, I/O configuration and restbus simulation. At the same time, the engineers of Porsche Engineering are also researching and working on artificial intelligence (AI) applications that will effectively support and assist testers with their tasks. This will enable future testers to focus more intensively on their actual challenges in the development of the function software.

Conclusion:
Testing effectively saves money and time

Testing is often neglected on the pretext of saving time or costs. However, practice shows that testing is actually one of the most effective means of saving both resources and time. Above all, tests minimize the risk of detecting faults at a late stage in the development process—or even only when the product is in use by the end customer—when corrections are exceedingly costly.

Porsche Engineering relies on extensive and intensive testing on HiL test benches for the ever-more-complex control units in vehicles. This enables:

- Enhanced quality of the end product despite cost- and time-savings—while the validation of the functionality of the hardware and software in parallel to the product development process yields high efficiency
- Cost savings and lessened use of vehicles as HiL test benches are more readily available and can be adapted to conditions more quickly
- Quicker provision of a drivable prototype—not to mention with a higher SW and HW quality
- Quicker achievement of operational state for components such as actuators and sensors. Timely validation of functions and diagnoses minimizes the risk of (total) system failure—for instance a destroyed transmission, defective engine, etc.

TESTING

From motor racing to series production

Text: Emmanuel Dhollande
Photos: Markus Bolsinger

With an in-house-developed test system for battery management systems (BMS), Porsche Engineering is making high-voltage technology for hybrid and electric cars fit for victory on the track and inspiring series vehicles—while expanding testing capabilities, shortening development cycles and minimizing development risk.

Without electronic control units, modern automobiles would not be possible. They fulfill increasingly complex tasks such as controlling engine, transmission and braking functions, and their numbers are rising continuously. This requires extensive development work both for the hardware and the software, whose functions during development have to be checked. For reasons of time and cost, real vehicles are not a viable option for these tests. Instead, automobile developers have been using "hardware-in-the-loop" testbenches, or HiL for short, since the early 1990s (see page 20). These test benches use computers to simulate the real environment, for example a car, and embed

the component to be tested in this simulation. The principle: During the test, the environment simulated by the computer—the car, for example—stimulates the inputs of the control unit with real sensor signals. The control unit responds by emitting control signals for the actuators to the computer through its outputs. This process closes a control loop.

Car development today is unthinkable without such HiL test benches. The tool makes it possible to test recurring processes under the same conditions, enables drastically shortened development times and saves costs.

Tests on the real control unit

For some components of electric vehicles, however, it can be beneficial to develop special variants of these HiL test rigs that fulfill the specific requirements of electric vehicles and enable further efficiency gains due to their flexibility and portability. While conventional HiL test benches do also work with real sensors and actuators, they need the indispensable high-voltage equipment required for electric drive units.

For such cases, Porsche Engineering developed a portable HiL test rig for battery management systems (BMS)—the BMS Mini-HiL. Here only the control unit to be tested is actually connected—the entire periphery is emulated. This means that the control unit mirrors to the BMS that it is connected to a real battery and real actuators and sensors. In reality, it is only mimicking these components.

Using this miniature test bench, which was deployed for the first time for the BMS of the Porsche Le Mans prototype, the 919 Hybrid, it becomes possible to test states like cell overload or a malfunction in the communication between the cell controllers—on a real BMS control unit and not only in the MiL (Model-in-the-Loop) or SiL (software-in-the-loop). The test rig can be used by the software developer or tested on a desktop and replaces the battery environment—with a shortened development cycle.

The concept of the BMS Mini-HiL

The setup of the BMS Mini-HiL is as follows:
The BMS to be tested is integrated as a real component. The inputs and outputs are connected with internal plug-in cards that emulate all sensors and actuators. The BMS Mini-HiL can then be controlled via an external rig on which a battery simulation, for example, is running. This simulation supplies the input for the components that are being emulated.

This set-up requires little space. So the format of this test rig can be considerably smaller than

Comparison of various test rigs from the perspective of the BMS	HiL	Vehicle	Mini-HiL
Use	Qualification of hardware and software	Qualification of the entire system	Focus on software qualification—Safety functions that cannot be tested with a conventional HiL
Framework conditions	High-voltage rig	Prototypes	Workplace
Principle	The test subject incl. sensors and actuators is used. The battery and cells are emulated by mains power supply units.	Real battery with real components.	Sensors and actuators of the test subject are emulated.
Costs	High	Very high	Low
Scalability	Low	High	High
Intervention by developer	Low	High	High
Simulation of internal sensors or actuator faults	Very difficult to impossible as real components have to be used.	Very difficult to impossible as real components have to be used.	Internal errors can be simulated through the emulation of components.

1 **Porsche Engineering's Mini-HiL is ideal for testing battery management systems:** It does not require a high-voltage environment or real sensors or actuators. Tests can thus be carried out quickly, they are cost-effective and very conclusive, and they shorten development times.

conventional HiL test benches. Indeed, the BMS Mini-HiL only takes up roughly as much space as this magazine when opened. It can easily fit on a desk, enabling the developer to keep the test rig within a reachable distance at all times.

Comprehensive testing capabilities

As the BMS "believes" itself to be embedded in a battery, the tester can measure all values just as they would occur in a real battery environment. But it can also test all system states and measure their effects, including states that would be difficult or impossible to create in a real battery or which would damage or even destroy the battery in the process. This includes overvoltage states, for instance.

Even defective cell controllers and other defective components can be simulated without damaging the integrated circuits (ASIC—application-specific integrated circuits). This enables the developer to quickly and inexpensively test whether a simulated defect leads to a precisely defined reaction that protects the system. Indeed, any type of behavioral fault—a communication error, for example—can be fed into BMS Mini-HiL in a targeted and precisely calculated form and the reaction to it can be measured.

To perform its function, the Mini-HiL must evaluate the electric interfaces (inputs and outputs) of the test subject (BMS). A typical scope would include:

Inputs

- Terminal for supplying the logic and contactors (electromagnetic switches such as a relay, but designed for higher switching capacity and greater safety)
- The pilot line, which in a high-voltage battery secures all high-voltage plug connections
- The crash line, which in case of a crash ensures that the high-voltage system automatically goes into a safe state
- Temperature sensors within the battery
- Strings of cell controllers of the latest generation
- Current sensors
- High-voltage sensors
- Pump of the cooling circuit
- Control line of the contactors
- Diagnosis contacts, if necessary

Outputs

- Monitoring of the contactor states
- Monitoring of all other electrical outputs

The inputs must be fully controllable either by the user or automatically via a CAN network. One typical scenario, for example, is the simulation of an open pilot line or the simulation of a cell controller error. Moreover, the outputs must be monitored and their statuses output via CAN. This makes it possible to check when a contactor is physically triggered.

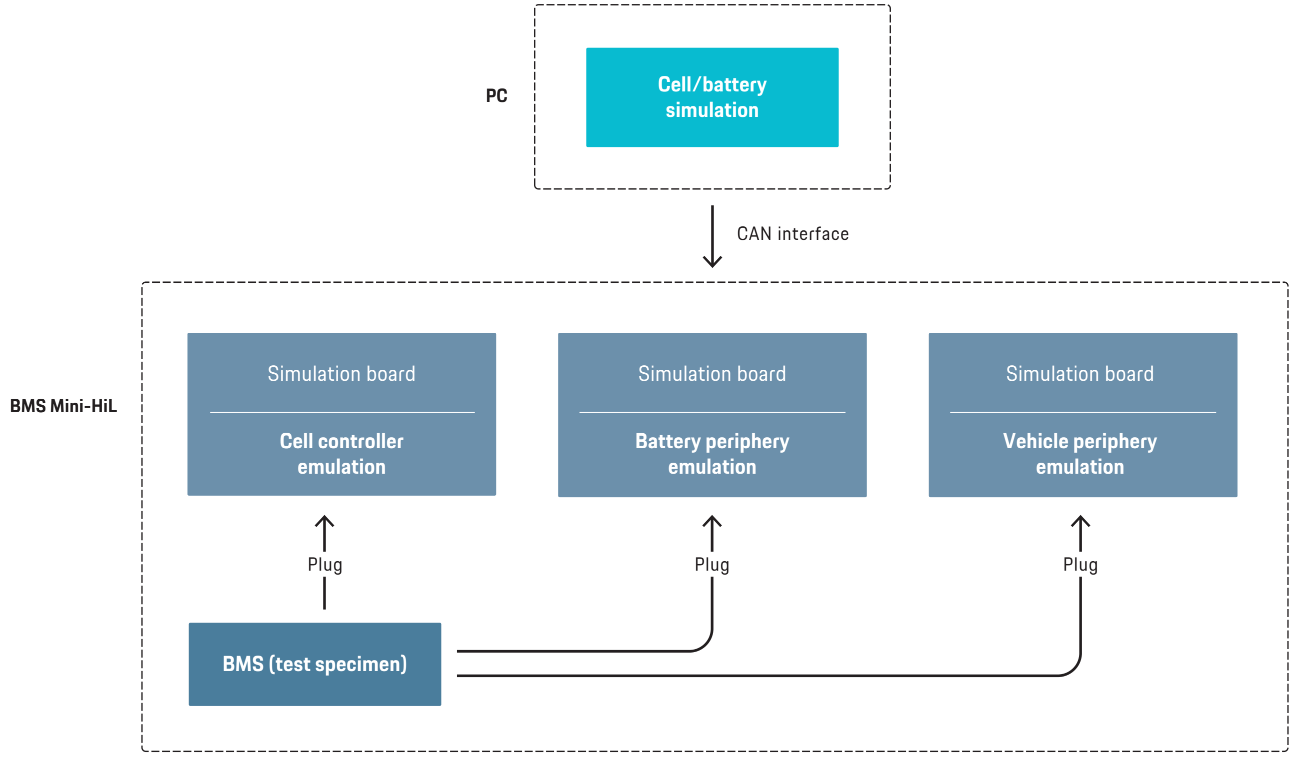
Variable hardware

The design of the hardware was devised as a largely variable system and thereby partitioned into different hardware components. In a 19" housing, multiple connection slots enable the connection of plug-in cards with hardware components for concrete tasks depending on the task at hand. A backplane (bus board) with multiple connection slots as the back wall of the housing provides the plug-in connections for these assemblies' plug-in cards and connects them electrically so that they can communicate with each other.

In the BMS Mini-HiL, a car simulation plug-in card, for example, enables the connection of the typical vehicle interfaces, such as the crash line, pilot line and more. A battery simulation plug-in card handles the connection of the typical internal battery interfaces (contactors, high-voltage sensors, etc.). A connection plug-in card connects the backplane with the test subject connector.

Full variability: A development team adjusts the Mini-HiL to new hardware. Doing so is a simple matter of swapping out plug-in cards.

2 **Emulation versus simulation:** If one wishes to map the overall behavior of a sensor on the hardware level, one speaks of an emulation. The emulated sensor behaves identically to the real sensor (same protocol, same reaction time). If one wishes to represent the physical or thermal behavior of a system, one speaks of a simulation. The Mini-HiL emulates elements such as cell controllers through the interaction of hardware and embedded software. The voltages and temperatures that the emulated cell controller is to measure, however, are simulated by a physical cell model.



The advantage of this modular design: If the hardware of the test subject (BMS) changes during development, no new hardware design of the Mini-HiL is required, as it can be quickly modified by simply swapping the plug-in cards.

Elaborate emulation of the cell controller

The most critical challenge of the project was the emulation of the cell controllers. These controllers are of the latest generation and feature numerous complex security functions. The battery of the future electric sports car, the Mission E, is based on cell controllers that probe cell voltages and temperatures extremely rapidly. So the cell controller emulation must enable a reaction time of less than five microseconds.

This exacting requirement impacts the hardware and the software architecture. To represent the various cell controller strings in the battery, the engineers opted for a multi-processor solution in the hardware responsible for it.

The software development for the emulation of the cell controller represented a major challenge as the latest generation of cell controllers feature many internal registers and integrated self-test functions whose communication is secured by various mechanisms. The spectrum ranges from checking measured values to redundant measurement of integrated multiplex or measuring components.

Powerful software architecture

The software architecture was modeled using UML (Unified Modeling Language). The focus was on the static (class model) and dynamic analysis (sequence diagram, automated status function). Then the architecture was implemented with the particularly suitable object-oriented programming language C++.

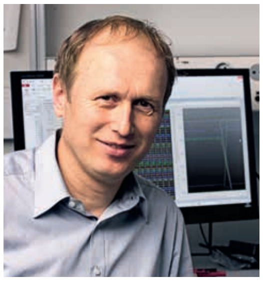
Software for the battery model

The battery model was initially written by developers in the technical/scientific software for numeric calculations, “Matlab Simulink” (MathWorks). It maps the dynamic, electrical and thermal behavior of the cells and the battery with a dynamic energy load depending on the state of charge and the state of health. So the tool simulates a cell on a PC, mapping its behavior when it is discharged and the voltage drops and when it is charged and the voltage rises.

After converting this model into an executable file (compiling), it was embedded in a software that has proven particularly well suited to the development, analysis, simulation, testing, diagnosis and commissioning of control unit networks (CANoe from Vector Informatik). As a result, all target cell voltages and target cell temperatures are sent via a high-speed CAN network. These values can then be read out by the BMS in real time via the protocol of the emulated cell controller.

“The emulation of cell controllers of the latest generation was the biggest challenge.”

Emmanuel Dhollande, Porsche Engineering



The end user still has the ability to feed in errors in a targeted fashion. At the press of a button, defective contactors (contactor does not trigger), insulation faults and many other faults can be simulated.

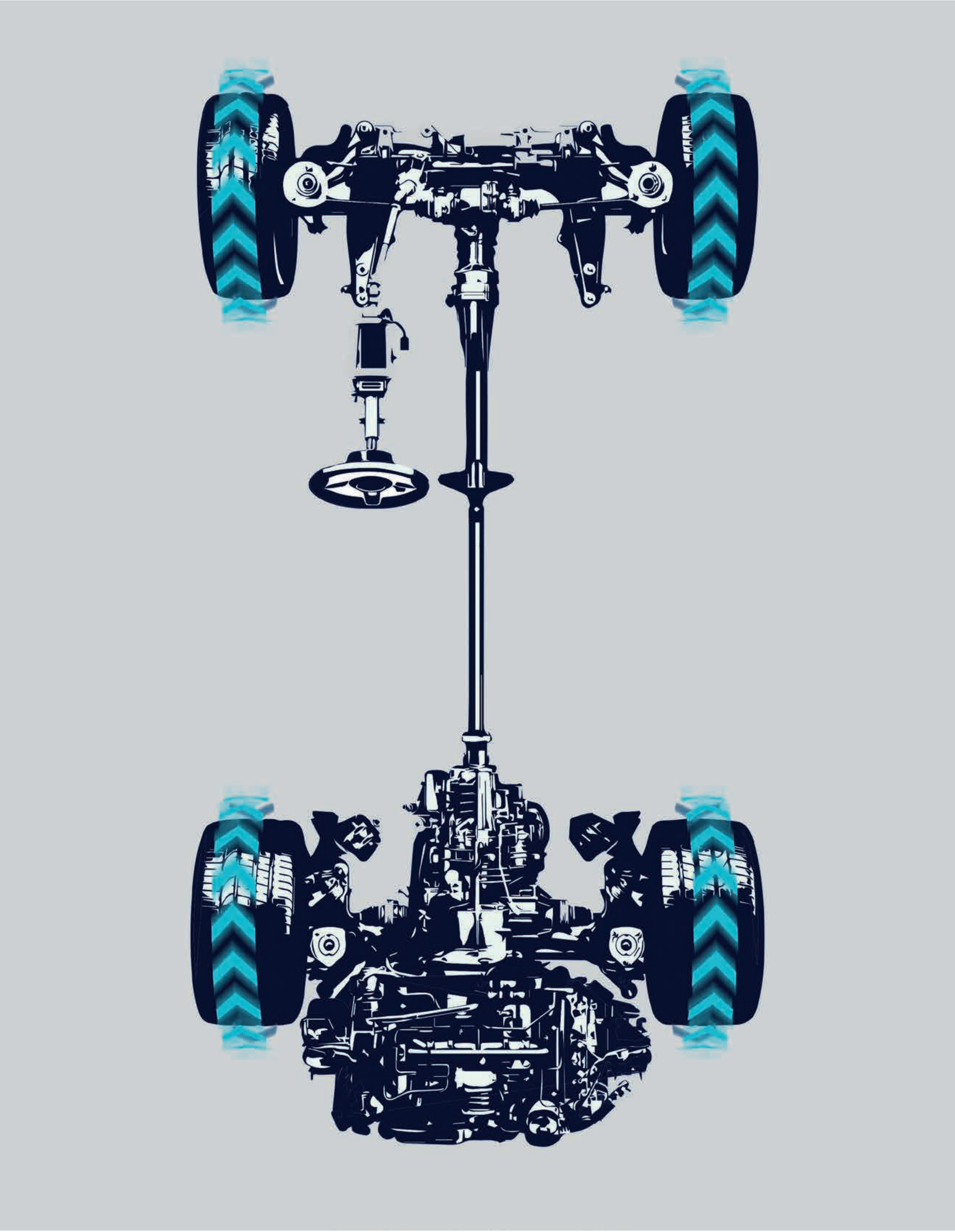
Automatic tests with EXAM

Another goal was to have time-consuming test series run automatically with the Mini-HiL, for example over the weekend. For the test automation, the EXAM (Extended Automation Method) from the MicroNova company is used. Through the consistent use of an abstraction layer, the EXAM test cases that were written for the existing HiLs can also run on other processor architectures and thus also on the Mini-HiL. The BMS Mini-HiL can also be used to emulate various internal defects of the cell controller that are not conducted in the vehicle or in the HiL where real controllers are used. By employing software-based emulation of the controller, the Mini-HiL offers a major advantage in this respect.

BMS Mini-HiL a component of other HiLs

The BMS Mini-HiL can also be integrated into another test rig, such as a vehicle HiL. This makes it possible to test the BMS in the complete vehicle environment as well. Thanks to the simulation of a defined environment, this enables networking tests for the BMS as well (CAN, FlexRay, etc.), in all operating modes of the control unit (standby, high-voltage, charging, etc.).

In brief: In order to test the growing software scopes for control units, it is frequently useful to emulate the behavior of sensors and actuators. A portable HiL test rig with a real control unit (hardware, software) that emulates the entire periphery shortens development cycles, expands testing capabilities and minimizes the development risk.



TESTING

A measure of power

Text: Uwe Brenndörfer, Marco Glink
Photo: Porsche AG, Illustration: d3

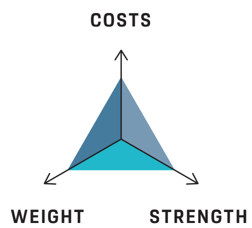
In vehicles based on a motorsports design, the powertrain has particularly tough requirements to meet. And the bar is constantly being raised: Modern plug-in hybrids need more and more drive components to fit the limited installation space, with the components required to produce more and more power without compromising reliability. As new materials and production methods are discovered to help achieve this greater power density, testing becomes ever more important as an approval tool—only standing up to the tests will prove what is destined to get a new generation of vehicle moving.

These are the challenges that drive the engineers at Porsche Engineering to excel. Testing requires them to define loads that are representative of day-to-day use and to figure out scenarios for applying these loads to the separate components and assemblies. All relevant loads and functions need to live up to requirements and testing aims to verify this within the shortest-possible time frame. To do so, the engineers employ all manner of instruments, from simulation to engine bench to test drive.

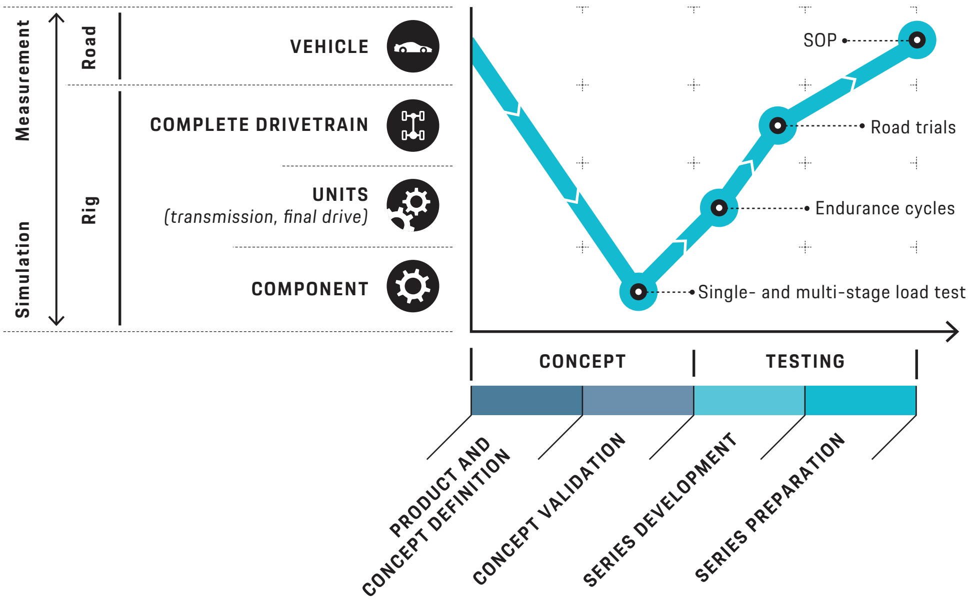
Starting point: simulation

Simulations use physical and behavior-based models of driving environment, driver and vehicle. Modern computer models, such as Porsche Engineering uses, possess a depth of data accumulated over decades. They allow reliable depiction of highly complex OEM requirements, for example the capacity to use a powertrain in a variety of vehicle models. To identify in sufficient detail the load profiles for powertrain components across a variety of product applications, simulating what are referred to as load collectives is indispensable. The load profiles invariably produce conflicting interests in terms of strength, weight and costs. These conflicts need to be resolved before the second step, in which design collectives are drawn from the various load profiles. The design collectives are themselves in turn used to dimension the units that will form the module system.

This process is highly dynamic because its application itself modifies and refines a vehicle's driving and comfort qualities. These changes to driving characteristics can result in considerably increased component strain and exceed the design's failure limits. These findings are then fed back to simulations of component load using new application data to calculate load collectives. Without ever using



Balancing act: When designing the components, you need to resolve the conflicting interests of weight, strength and costs.



Simulation and trials during product development. Validation begins with the separate components and ends with the finished vehicle.

Uwe Brenndörfer
Test engineer for drivetrain trial strategy

Marco Glink
Test engineer for drivetrain load collective measurement

any actual components, an iterative process continually compares the load collectives with the design collectives to identify necessary modifications.

Engine bench trials under maximum load

The very first prototype components can already be used for engine bench trials. Usually, components are subjected to short-duration trials that examine various factors at a highly accelerated rate: oil supply, bearing load, tooth-flank load, tooth-root load are tested in regard to the design's failure limits in defined stages up to component failure. This kind of testing is extremely component-specific and can only convey a limited level of information. What it can tell you, however, is whether a certain design actually works at all.

Once development progresses further, full units become available for trials. What is referred to as endurance cycle testing has proven particularly suitable. It tests loads at a comparatively accelerated rate while at the same time supplying highly reliable data on a unit's sub-components. During testing, the subcomponents are put together as a unit consisting of combustion engine, traction motor, transmission, control units, drive shaft and half-shafts. Tire contact with the road surface is simulated using consumer units.

By employing actual control units for engine and transmission, the engineers can examine application data sets in direct conjunction with the powertrain. Here, too, the goal is to identify the failure limit under a simulated powertrain load. Intelligent online control of the differential coupling ensures correct distribution of drive torque to the front and rear axles. With the test run progressing further, online adjustments to gradient resistance allow compensation for variables like changes in drive power or system efficiency due to tribological variations or wear of components and lubricant fluids. As a consequence, the powertrain reaches a high level of maturity even before its first use in a prototype vehicle.

Real-time testing

The most accurate depiction of all powertrain components' wear is achieved by performing real-time tests on a vehicle test stand, although this method is by far the most time-consuming. Such testing supplies the most reliable data on all components. Real-time testing can be based on driver models that incorporate vehicle parameters or be based on real driving data measured in a trial vehicle.

Real-time testing does not progress at an accelerated rate but does, however, take into account the entirety of driver variables and the ambient conditions of the acceptance trial. The test uses vehicle speed and output speeds as setting variables. These values can be specified either directly as velocity or artificially through a driving profile. The aim is to minimize the potential for error at the least-possible deviation from the specified targets. Though no online adjustment of driving resistance is available for compensation, intelligent driver models facilitate dynamic real-time tests. The model's driver logic decides autonomously whether to emulate the speed profile or to drive freely within the specifications of an allowed speed range.

Real-life driving trials require the vehicle to possess a certain degree of maturity. The vehicle needs to be minutely examined to ascertain this.

Road trials and extensive measurement work

15,000
kilometers of test driving within three weeks.

Up to
600
signals per second.

While the powertrain is under development, overall vehicle design continues, too. Consequently, real-time testing on the test stands is supplemented with measurement data from test vehicles. Road tests are held in actual road traffic and on dedicated test sites, for example in Nardò. When performing vehicle measurements, Porsche Engineering aims to obtain data of sufficient statistical reliability on what the characteristic powertrain loads will be in everyday vehicle operation over driving distances of up to 15,000 kilometers. The test drivers drive only on dry roads during the trials as dry conditions entail the greatest material stresses. Measurements take into account all essential variables, including route composition, driving style and vehicle cargo. The engineers subsequently evaluate the measured values and derive load collectives for precisely defined customer usage profiles.

Measuring equipment—sturdy but sensitive

The measuring equipment for the road tests is designed to be impervious not only to usual day-to-day driving but also to the extreme loads produced by abusive handling, for example like what engineers call a “performance start.” To obtain measurement data from vehicle operation over a period of three weeks and a distance of 15,000 kilometers, the measuring equipment used is particularly reliable in terms of system startup, redundancy and storage capacity. The primary focus of load-collective measurements are wheel torque values. Together with the gear ratio, wheel torque allows it to determine precisely what loads the powertrain is being subjected to and what damage this is causing on the powertrain's various components. What makes these measurements so difficult are the rotating parts (which can only be measured using sliding contacts or telemetry), the powertrain moving in all directions at once, the temperature effects (heat radiating from the exhaust system, transmission or engine), electromagnetic interference (EMC), and the effects of the weather.

The measuring instrument used here is what engineers call a measuring flange. Because of their high component rigidity, measuring flanges are especially resistant to abusive loads (performance start, µ-split).

Road trials also use these measuring instruments:

- Acceleration sensors that record vehicle acceleration along the x-, y- and z-axes
- GPS receivers that determine position using longitude and latitude as well as elevation, gradient, and curve angle and radius
- Thermometers that measure the ambient temperature, component temperatures, and the temperatures of the operating fluids

Large data volume

Digital measurement values primarily describe the communication signals exchanged among the control units via the vehicle's bus system. While only a few years ago a low number of CAN systems sufficed to ensure data communication, more recent vehicles additionally utilize the FlexRay system. FlexRay's architecture allows it to transfer far larger amounts of data. The measurement sequences' signal scope usually lies between 100 and 600 signals mea-

All the way to breaking strain: A drivetrain is not considered ready for mass production until every last test on road and test circuit has been fully passed.

sured at a rate of between 500 hertz (torque) and one hertz (temperature). To record the data, Porsche Engineering employs powerful data loggers designed for large volumes of data and high transfer rates. Transmission development requires additional transfer protocols (for example XCP, CCP).

The system is started by means of a central switch that controls a central power supply system capable of serving all amplifiers and sensor blocks. This is intended to prevent any incorrect measurements being made due to the system components inadvertently remaining deactivated. The same also applies once measuring has been completed: any components inadvertently remaining switched on will discharge the vehicle battery before the next measurement run begins.

Precise route tracking

To reduce data loss during measuring, there are specific saving points along each route that the drivers are required to observe. This way, should the measuring equipment encounter problems between two waypoints, only the incorrectly measured route section will need to be repeated rather than the entire route. However, this results in multiple files for each measurement run, which need to be merged again in a subsequent step. Measurement data is correlated to route type by means of a route signal, for example generated from GPS coordinates when on a mapped route. Another method is to generate a route signal using additional measured values (speed, steering angle, acceleration and others) that are then computed in a complex process. This produces a highly dynamic signal capable of processing specifically even standstill times in a traffic jam or when driving in urban areas. If blocked roads force a driver off the planned route, different measurement records will no longer correlate. In such cases, this method allows automated allocation of a route type (for example city, country road, freeway).

Processing the measurement data

Over the course of measurement, a number of measuring errors can occur resulting from the nature of the systems used. These need to be rectified during a subsequent follow-up and of course before any measurement data is handed over to customers. Such measurement errors result first and foremost from flaws in the measuring flanges and shafts used to record torque and include torque offsets, calibration skips, spikes, drifts or “no-values.” Because—due to the sheer volume of raw data—manual rectification of these measurement errors would take months, Porsche Engineering has automated detection of these kinds of errors. Unusable data is removed by search engines, eliminating the need for manual validation of the data sets. All this aims at one thing: to supply the customers as quickly and as efficiently as possible with the reliable data required for designing and configuring an essential vehicle assembly. Porsche Engineering is fully aware of the great responsibility this entails and takes it on with confidence in every project.

Outlook

Porsche Engineering pours its time and resources into keeping its testing scenarios at least one step ahead of tomorrow’s automobile technology. Specifics include the programming of simulations that depict driving loads in even greater and more varied detail. Automated driving is set to greatly affect the composition and severity of powertrain loads in future, opening up potential to, for example, utilize load reductions for tailored lightweight design. Our cutting-edge testing incorporates these considerations, just as it incorporates considerations on how future human behavior is likely to shift test parameters.

Sensors are installed in the seat rail to record acceleration.

GPS determines position for route tracking.

Thermometers measure ambient temperatures, component temperatures and fluid temperatures.

Porsche 911 Turbo S Cabriolet

CO_2 emission (combined): 216 g/km
Fuel consumption, urban: 12.1 l/100 km
Extra-urban: 7.6 l/100 km
Combined: 9.3 l/100 km
Efficiency class: F


All-round testing in a perfect circle.
Nardò Technical Center.
Visit www.porsche-nardo.com for more information.

TESTING

Testing the mobility of the future

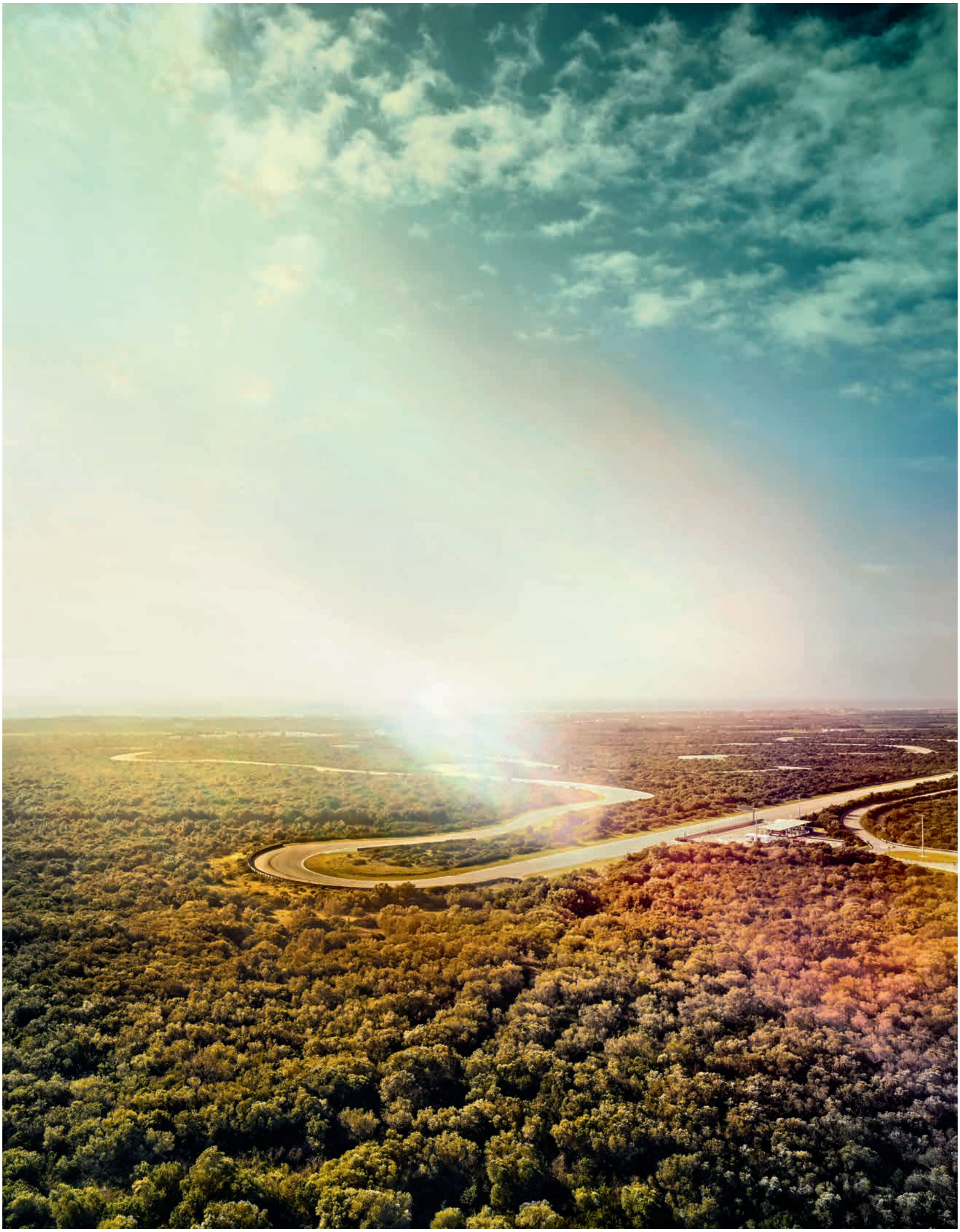
Text: Peter Lincoln
Photos: Heiko Simayer

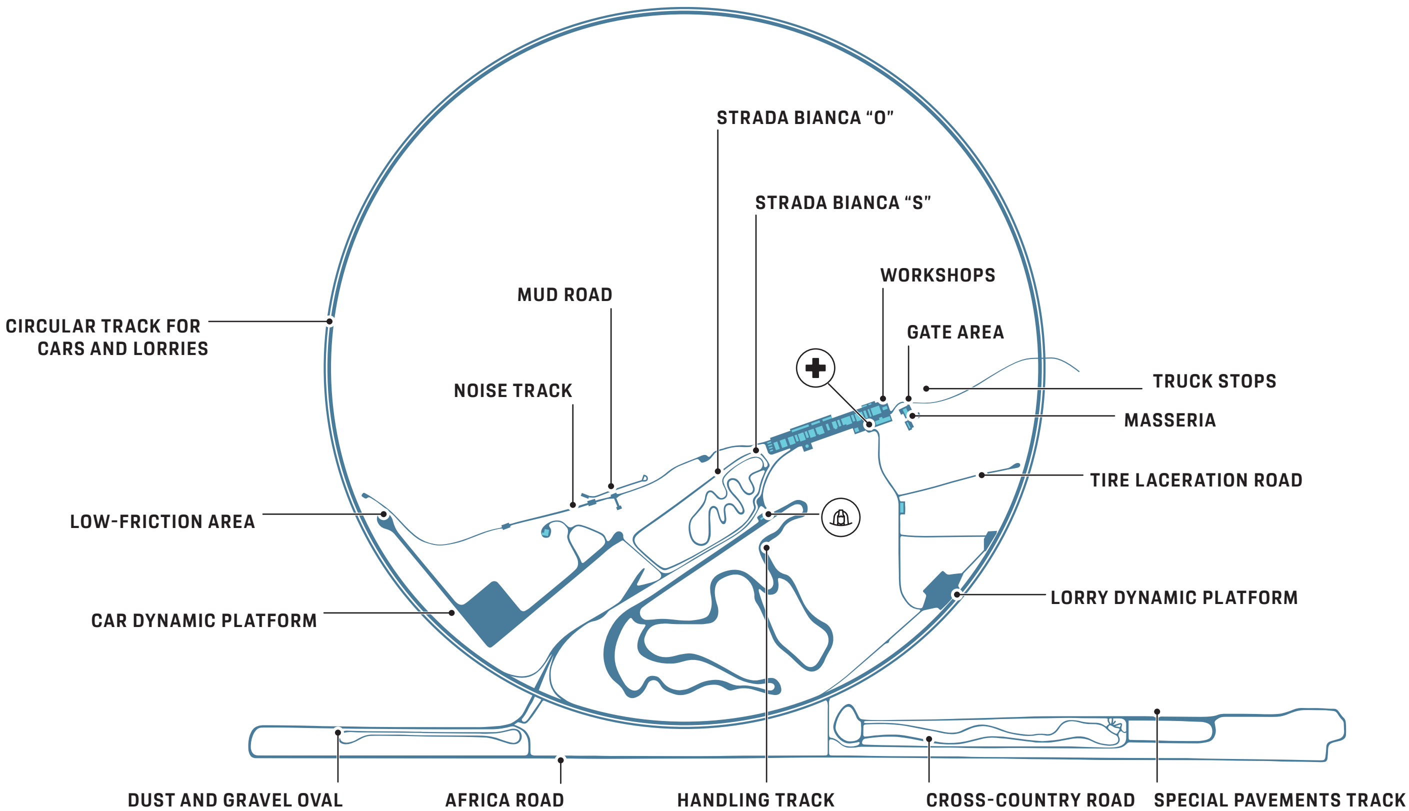
Where Italy's atomic physicists once wanted to build a particle accelerator, test mules and prototypes have been put through their paces for decades. The Nardò Technical Center is gearing up for testing the mobility of tomorrow.

The rising sun casts long shadows. The over-12-kilometer circular track for which the Nardò Technical Center (NTC) is justly famous throughout the world is already being used for test drives in the early morning hours. At a speed of over 200 km/h, the driver casually removes his hands from the wheel. The gently rising lateral incline of the track compensates for the centrifugal forces, creating a neutral driving sensation at speeds up to 240 km/h that requires no steering. Acquired by Porsche Engineering in 2012, the testing grounds are being comprehensively enhanced to secure Porsche Engineering's extraordinary position for the future as well. The mobility of tomorrow, with autonomous driving and electromobility, will also bring additional challenges for the testing grounds and its over 150 employees. Porsche Engineering has therefore been intensively laying the groundwork for the future at the NTC with new ideas that will enable it to meet the challenges to come through continuous development. Development that will pay dividends. The NTC, after all, is a one-of-a-kind facility worldwide—a quality grounded in its history.

One of a kind worldwide—then, now and in the future

No one was thinking of automobiles back in the 1960s when land surveyors in the southern Italian region of Apulia marked out a circular plot of land with a diameter of four kilometers and a circumference of 12.6 kilometers. They marked out this massive footprint for a particle accelerator aimed at propelling Italy's atomic physics to state-of-the-art levels.





But the atomic plans of the Italian state changed. So rather than welcoming nuclear physicists, since 1975 this small city of 31,000 inhabitants way down in the heel of the Italian boot, Nardò, has instead played host to a steady flow of visitors from the automotive industry and experienced a powerful boost to its retail trade, tourism and employment figures in the process. For instead of atoms hurtling in a circle, a now legendary high-speed track for cars was built. This, the fastest circular track in the world, is flanked by over 700 hectares of grounds encompassing more than 20 test tracks for every conceivable stage of testing, workshops and trial facilities for cars, trucks and motorcycle manufacturers.

Thus, the Nardò Technical Center not only offers the Porsche company, but also countless clients from around the world, unique testing and trial facilities. And they are popular indeed. Some weeks up to 600 guests go about their business on the grounds. They come to conduct exacting test procedures and test drives requiring the utmost concentration.

One of a kind: The high-speed track is circular—the original idea was to build a particle accelerator for nuclear researchers.

12.6 km
in circumference.

4 km
in diameter.

People are at the center of the enterprise

The provision of modern working environments enjoys the highest priority. Many of the aging workshops have already been gutted, renovated and re-equipped. The administration building, the Masseria, has also been completely renovated, though with great pains taken to retain the charm of the old structure while modernizing it. The same applies to the central tower, from which the track was monitored for decades. It is a water tower, and was kept as a landmark structure. The objective is to recognize the requirements of the future and implement them with respect for tradition. That commitment sometimes shows up in small details as well: In modernizing the reception building for truck drivers, an ancient pizza oven was deliberately retained rather than being replaced.


NARDO TECHNICAL
CENTER
12/12/17 07:07

Ready for action with the rising sun: Testing on the numerous available test tracks begins in the early morning.

All safety questions answered

Another factor much appreciated by clients is the discretion of the Nardò Technical Center. After all, the work here—as in every aspect of Porsche Engineering—is subject to the strictest confidentiality. What happens in Nardò stays in Nardò. That, in sum, is the simple formula. Clients' data, drives and vehicles are afforded the best possible protection.

Yet the topic of safety has a further dimension as well: ensuring the safety of every visitor to the grounds of the NTC. After all, whatever is tested can also fail. And the track has to be all the better prepared for that reason. That is why track cleaning duties, for example, are handled by an airport cleaning machine whose suction aerodynamics were so improved by Porsche Engineering that it can now travel the track at 40 km/h rather than 20 km/h as before. This makes it possible for the asphalt to be cleaned of tire residue, which would otherwise compromise grip in the corners in particular, very quickly. This removes a factor that could otherwise pose the risk of falsifying measurement results or even present a physical hazard.

Porsche Engineering also optimized the fire engine, equipping it with the latest rescue technology for use at the NTC. Together with the safety car, which is based on the Panamera Turbo, it is available around the clock, always staffed with trained emergency personnel. The third link in the safety and rescue chain is represented by the ambulance based on a modified Porsche Cayenne. It can reach any point at the NTC from the new Medical Center in just three minutes. Two emergency personnel who are intensively trained for the fast emergency response vehicle are on call to render help around the clock. They do alternating duty in Stuttgart and Nardò and don't even have to adjust: The rescue vehicles are identically equipped in both places. All medical facilities are also state-of-the-art.

The team gives a great deal of thought to making prevention even better as well. Drivers at the NTC can rely on a perfectly monitored track. The facility has already implemented a track management system that is currently being tested and can centrally control and monitor the vehicle tests. This includes video tracking, GPS tracking and radio communication with the safety director with seven communication channels. Only a safe testing environment enables complete concentration on the work.

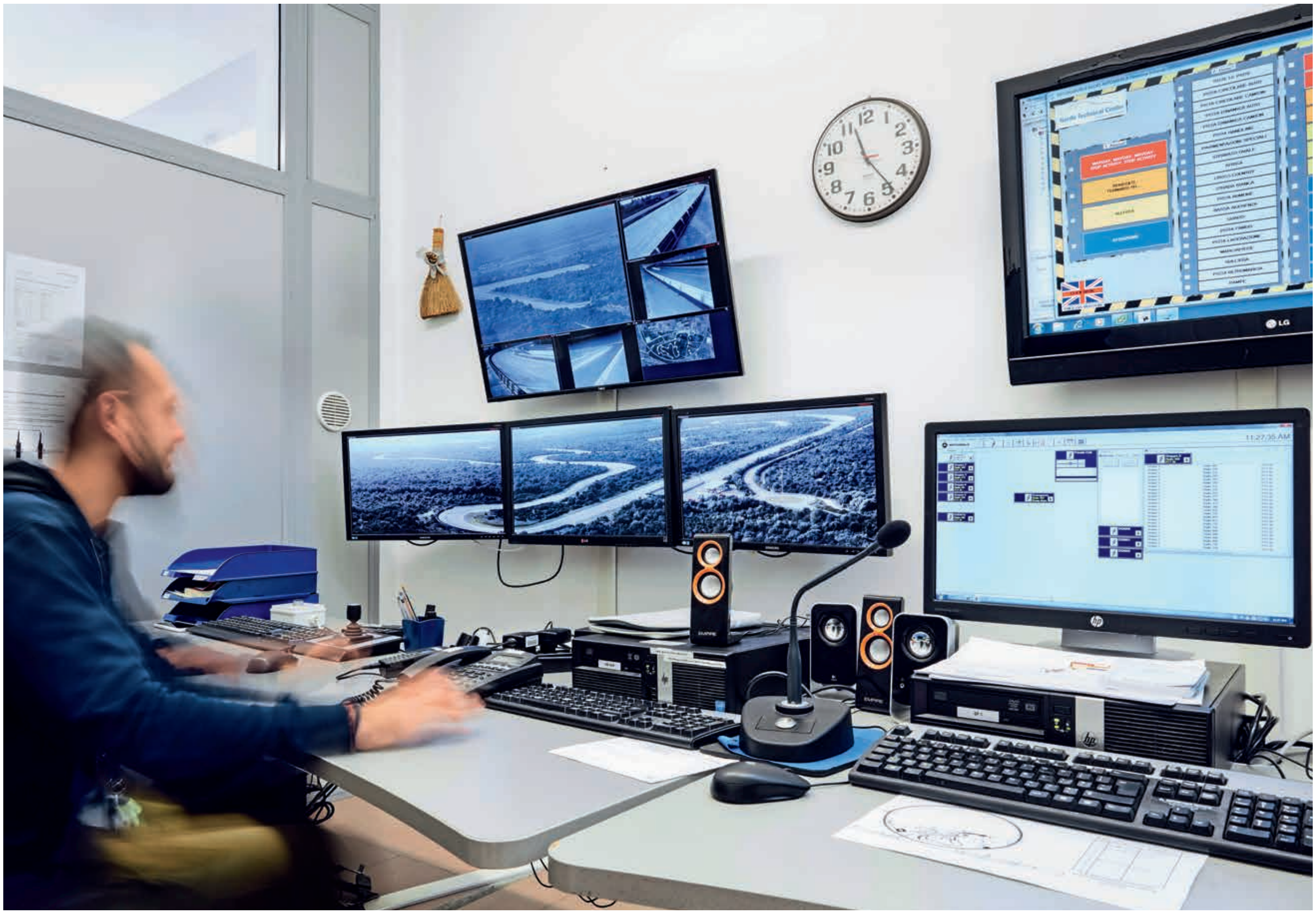
Some renovation plans were initiated based on customer wishes.

High-tech lab for vehicle manufacturers

But the master plan for the future of the NTC is not just geared toward safety, but also based on a precise analysis of all relevant conditions. Asphalt and concrete are tested for their abrasion values, for example, and compared to the materials used in road construction. The objective: Every surface used in Nardò should correspond to what is common on the road surfaces of the world. And there have been changes in that regard over recent decades. It's also key to modernize other workshops and enhance the logistics system. Some of the conversions can be traced back to client requests. An additional wet handling track, an incline hill and a lane-change straightaway in the high-speed area are at the top of the list.

In order to provide appropriate testing options for autonomous driving as well, the NTC will break new ground. Modern facilities for driver assistance systems are intended to create a perfect environment for these systems. New technologies, after all, require new testing methods as well. The NTC sees itself at the forefront of these developments. The Nardò Technical Center will soon be a laboratory in which clients can draw on a digital infrastruc-

Safety first: The tracks in Nardò are monitored centrally—via video tracking, GPS tracking and radio communication.



ture that ensures secure data analysis in real time. The digital revolution of driving needs fast electronics all along the test track. The circular track is therefore being outfitted with technology that guarantees end-to-end V2X connectivity. This allows vehicle data to be transmitted, processed and analyzed very rapidly during test drives.

Future plans also include all facilities that will be required to enable testing of electric vehicles. This ranges from special workshop equipment to high-capacity charging stations that quickly get electric cars back out on the track. Changing battery packs using purpose-built lifting rigs? Inductive charging? The insights leading to the most efficient solution only mature in dialog with the clients. Porsche has long since recognized all of these challenges and is now resolutely implementing solutions to them in Nardò.

The environment and the region

Throughout the course of all these modernization measures, Porsche planners never lost sight of one thing: their responsibility for the people and the region around them. As over 90% of the people who work here full-time are from here, supporting the region is all the more important. The NTC is increasingly working with local suppliers and employing ever more people from the region. Relationships with local authorities and the university have also grown steadily over the years.

The commitment to the region extends to environmental protection as well. Renovation work aimed at lowering energy consumption is currently under way in the workshops and offices. One aspect of the renovations is replacing oil heating systems with highly efficient electric heating and cooling systems and using LED lamps for illumination. Moreover, the entire vehicle fleet was replaced to enhance environmental performance. Even more thoroughgoing measures are planned for the future. One measure currently being pursued is the search for an even more environmentally friendly energy supply. So all methods of generating energy are also under the microscope. Solar and wind power are set to play a larger role. And efficient energy storage methods, for example in salt-gel tanks, are also being pursued in Nardò too.

The NTC in numbers:

700
hectares in area.

153
employees.

300
visitors per day.

38
workshops.

Ideal working conditions: The workshops are modern and spacious. Nardò has all the facilities for testing electric vehicles as well.

History preserved: The Masseria administration building was completely renovated. Nevertheless, the charm of the old building was preserved.

In carrying out the renovation work, environmental principles are a primary focus.

Outlook: Real testing is indispensable

Although computer simulations now play a major role in testing processes, real-life testing of all processes under controlled and realistic conditions remains a crucial element in the success of mobility solutions. The variety of test tracks and facilities is already vast and highly attractive for most automotive manufacturers. In terms of quality and safety, very good conditions are offered to the clients. To be ideally positioned for the future, the facility is continuously enhancing its capabilities for new challenges and technologies. In Nardò, they've recognized the challenges that autonomous driving in particular poses in the testing context and they are creating precisely the environment that the developers will need in the years and decades to come.

The Nardò Technical Center is one of the most important and renowned test centers for vehicle manufacturers in the world. The core business of the Nardò Technical Center is its broad-based portfolio of testing services for its clients. From motorcycles to passenger vehicles and even heavy trucks—the NTC can offer a suitable test program for all types of vehicles.

With good weather conditions, the one-of-a-kind testing grounds offers testing capabilities 24 hours a day, 365 days a year. Clients at the NTC can conduct a large range of tests on different types of test courses. Over a total area of 700 hectares, the NTC offers its clients over 20 test tracks and facilities for a broad array of different types of testing activities. All tracks and facilities are characterized by the highest standards in terms of safety and confidentiality. A few examples: vehicle dynamics on the dynamic platform and the handling course, durability tests and reliability testing on the circular track, and fatigue tests on the off-road courses.


DMG MORI
Mobil 1
MICHELIN
WEC
MOTORSPORT

TESTING

The stopwatch makes the final call

Interview: Anja Rützel
Photos: Hoch Zwei/Corbis via Getty Images

Mark Webber has an impressive motor sports track record to look back upon. In our interview, he shares his thoughts on what makes a good test driver and talks about common ground and differences when it comes to testing racing and road vehicles.

Mark, race drivers ideally also make good test drivers to help engineers improve on race car design. How much time does a race driver spend test driving compared with race training?

— I'd estimate the ratio to be thirty percent testing and seventy percent racing. Although most race drivers aren't exactly keen on test driving, we all know it's indispensable if you want to improve the car. A test driver has to take the car to its limits in every respect. That's his job. It's the only way to get any meaningful data.

Does a race driver need to understand every last technical detail of their vehicle?

— No. It's useful, of course, to have a general understanding but keeping step with all of the complex technological progress is virtually impossible. That's why I find it most important to work on precisely those issues with the engineers that can actually help me improve—and learn new things in that regard. But drivers don't need to be technical experts, just like engineers don't need to be ace drivers.

"By now, the technicians can trace every little twitch your fingers make in the vehicle."

Mark Webber

When you're testing a race car, do you follow a predefined, detailed plan laid out by the engineers or is it more of an intuitive affair?

— Most test drives follow a specified, carefully worked out development plan. Lots of things get tested in advance, off-site. But once you're on the circuit, you don't muck around with bits and pieces. On the test track, you give it all the stick you've got. Of course, you still come across this or that interesting issue during test drives sometimes and then follow it up in more detail. I'd say it's eighty percent as planned and twenty percent freestyle.

Do engineers prefer to rely on their measurement data or on the race driver?

— The data is incredibly powerful, there's no denying it. And it's getting more and more significant. By now, the technicians can trace every little twitch your fingers make in the vehicle. But it still happens that the data doesn't match what my guts are telling me and, in those cases, it's really important to trust your instincts.

What general skills does every test driver need?

— They need to maintain a highly consistent driving style as there are loads of other parameters that keep shifting—tire conditions, grip and so on. So the driver's driving style needs to be absolutely stable. And test drivers need to have a healthy relationship with the engineers, there's no space for personal friction there. It needs to be like a good marriage. That's why you need to concede that the stopwatch makes the final call and not take criticism personally. Even if the engineering team were headed by my mother, if necessary I'd tell her "Mum, it ain't good enough yet".

What findings from testing race cars can you transfer to the development of series vehicles?

— Materials developments and tire technologies primarily. But technological advances like anti-lock braking and turbocharging came from motor sports back in the day, too.

How does testing differ for race cars and standard-production cars?

— Race cars need to survive in a competitive environment. So their tests are far more extreme. Standard-production cars focus more on safety.

Mark Alan Webber was born August 22,1976, in Queanbeyan, New South Wales in Australia. From 2002 till 2013 he drove for the Formula 1 teams Minardi, Jaguar, Williams and Red Bull, after which he moved on to the WEC top class LMP1 where he drove for Porsche and, together with his team mates Timo Bernhard and Brendon Hartley, won the Driver's World Championships in 2015. He retired from race driving in 2016 and has since been a highly sought test driver as well as a brand ambassador for Porsche.


Mission e

Electric pit stop

Text: Peter Lincoln
Photo: Jürgen Koch, Illustration: d3

For every purpose, be it in the parking garage, at the supermarket or freeway rest stop, Porsche Engineering has developed a fast-charging solution: a system with modular building blocks that takes account of the available electricity grid, visitor frequency and space constraints. For the first time, economic viability and user-friendly design are brought together in a charging solution that will help electromobility gain greater acceptance.

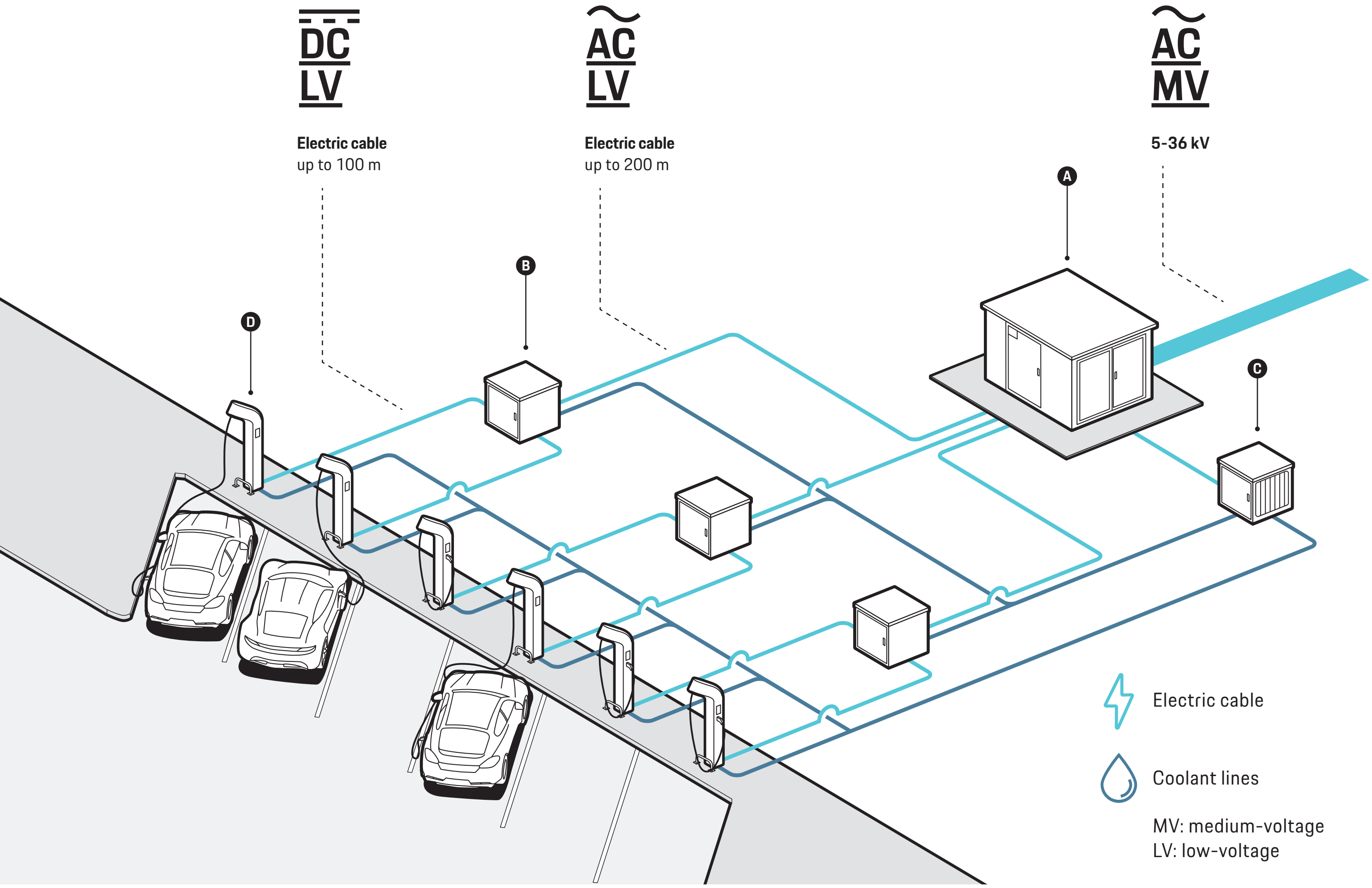
Looking at the fast-charging stations in use today, the disadvantages of the system are readily apparent at a glance. At present, all of the components needed for charging are installed in every single cabinet: transformer, galvanic isolation, power electronics, cooling and connectivity—significant outlays that make each individual charging station disproportionately expensive. So for Porsche Engineering, a charging park with a new system architecture and a new generation of charging stations quickly crystallized as an alternative. This new generation of devices is characterized by impressive fast-charging technology. It provides an attractive interface to the customer and, thanks to low operating costs, also presents a compelling business case for a wide variety of operators. The innovative charging park system (see figure 1) designed by Porsche Engineering also provides the capability to charge the batteries of multiple electric cars at the same time. Thanks to 800-volt technology, batteries can store enough energy for roughly 400 kilometers of range in just 20 minutes. Enough time for a coffee break at the rest stop or a few errands in the supermarket or shopping area.

FlexBoxes—building blocks of the architecture

The charging park system from Porsche Engineering is designed as a modular system comprised of standardized, weather-proof housings, the FlexBoxes (exterior dimensions: 120 x 120 x 130 centimeters). They enable flexible outfitting with all necessary components in a standard rack and can be positioned at quite some distance from the charging stations, for example behind a building or hedge. So both visually and in terms of noise, they are hidden from the customer. There are also ideal integration options for planned and existing buildings: The modules can be positioned wherever there is space, while the slim and user-friendly charging poles are optimally positioned for use by customers.

So in terms of space, there are no general prerequisites for setting up a charging park system according to the Porsche Engineering principle. One technical advantage for medium-sized to large charging parks is that a connection to the medium-voltage grid (up to 36 kilovolts of alternating current) exists. A transformer then converts this medium voltage into low voltage (local grid level). On the secondary side of the transformer, the same lower AC supply is always available irrespective of the location.

The intelligent design of the transformer also enables the accommodation of the galvanic isolation necessary for safety purposes. The benefit is clear: The centralized galvanic isolation obviates the need for it in each individual pole. Until now, it has been a part of the power electronics in all such poles, taking up space and driving up costs. Even for locations where this prerequisite is not in place, there is a transformer box solution available. This solution retains the major benefits of an optimal package and aesthetic design.



1 Fast-charging park

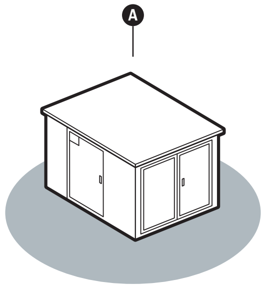
Thanks to an innovative architecture, electric cars can recharge quickly, efficiently and cost-effectively. A fast-charging park is also characterized by being highly economical for charging station operators.

Greater efficiency—lower operating costs

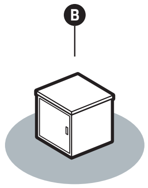
In addition to the lower system costs, the lower operating costs are also a substantial factor, for the Porsche Engineering charging park also functions more intelligently. The control server of the transformer station brings together all of the information from all control units of the hardware—comparable to a local network. This central brain checks and connects the control units for the cooling unit, the power electronics and the charging station. The control server also handles the communication with the back-end of the respective operator for settlement purposes. The result: Thanks to this innovative architecture, efficiency is boosted to over 95% for the complete system, which means the possibility of significantly lower operating costs compared to systems available today.

PowerBox

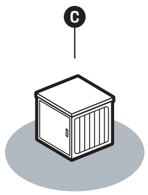
First, the low-voltage alternating current from the transformer station is converted into direct current in the PowerBox. The PowerBox can be equipped with two sets of power electronics and supply two charging points. The system utilizes silicon carbide (SiC) modules of the latest generation. The advantages compared to modules based on currently available technology consist in lower conduction, switching losses and space requirements. Moreover, elements such as line filters can be built more compactly due to the higher pulse frequency. The components are designed to accommodate a distance of up to 200 meters between the



Transformer
A transformer station with central galvanic isolation and a control server converts medium voltage into low voltage and works with high efficiency.

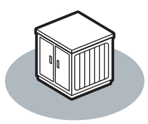


PowerBox
features power electronics for two charging stations and converts alternating current into direct current.



CoolingBox
keeps the entire charging park cool.

Charging station
for a high degree of functionality and economy.



ComboBox
Combined PowerBox and CoolingBox for a low volume of simultaneous charging processes.

transformer station and PowerBox and up to 100 meters between the PowerBox and the charging station. All in all, this results in the high flexibility required to position the components at any given location. Technically speaking, even greater distances would be possible, albeit with higher power losses and, above all, higher construction costs.

CoolingBox

Another important component of the charging park is the CoolingBox. The CoolingBox provides liquid cooling for the charging poles and power electronics. Every CoolingBox can accommodate two cooling units, each of which provides reliable cooling for multiple charging points under all operating conditions. On the exterior, a CoolingBox differs from the other FlexBoxes of the charging park system with its ventilation fins for intake and exhaust air. The CoolingBox is optimally positioned at some distance from the charging stations. This ensures that the unavoidable noises associated with cooling are kept far from customers' ears.

ComboBox—the alternative for small charging parks

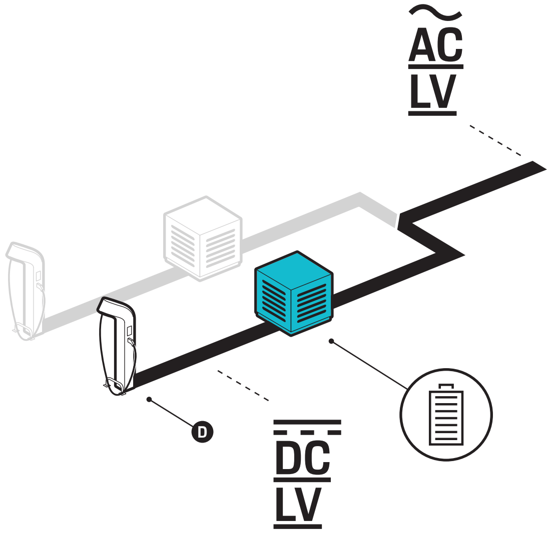
The Porsche Engineering development can also respond flexibly to the special requirements of charging park operators such as extremely limited space—for example at smaller locations. If the operator works with just a few charging points, a compact alternative system is offered: The ComboBox combines the PowerBox and the CoolingBox—a power unit with a cooling unit sufficient for one charging point each.

ChargeBox—fast charging even without medium voltage

Even for cases in which no sufficiently powerful grid connection is available, the modular charging system offers a solution with which electric cars can be charged extremely fast. Specially designed for this purpose, the ChargeBox (see figure 2) contains an additional buffer storage battery in addition to a power unit. This buffer battery is charged while no vehicle is using the charging station. Thanks to the storage battery as a replacement for grid power, the customer has access to high charging capacity at locations without medium-voltage grid connection as well. The ChargeBox is ideal for locations with a low charging frequency per day and in situations in which an expansion of grid capacity would be expensive.
The ChargeBox is available as an entry-level model with a 70 kWh battery and a 160 kW charging station. For more highly frequented locations, for vehicles with higher charging capacities or as a subsequent retrofit, there is also a fully equipped version with 140 kWh and two 160 kW charging stations, combinable for 320 kW. Another important element of the solution is provided by the smart grid unit at the grid connection point, which ensures that the system never draws more than the permissible amount of electricity from the grid. This component also helps with the use of electricity from an existing PV system for fast charging and supports consumption optimization efforts through energy recovery mode at the location.

Premium charging stations

The end customer notices nothing of the underlying technology. The same point of contact is always there: The charging stations are the single customer touchpoint with the driver of an electric car (see figure 3). Porsche Engineering designed the charging stations with the highest standards in terms of design and ergonomics for a positive charging experience while focusing in equal measure on the highest functionality and economy. As the engineers removed everything from the charging station that wasn't absolutely required at the customer touchpoint and packed it into FlexBoxes, a streamlined appearance could be achieved—and thus a typical Porsche design identity. That was, after all, an integral part of the design specs, aside from the universal applicability in all parking space situations.



2 ChargeBox

The ChargeBox is the ideal solution when there is no medium-voltage grid connection in the vicinity and relatively few vehicles will be charged daily. A ChargeBox can supply up to two charging points. In addition to the power unit, it contains an additional buffer storage battery.

Volker Reber
Senior Manager
High-Voltage System
Development

Florian Joslowski
Senior Expert
High-Voltage Systems
in the field of
Battery Matters

The crane-like shape of the poles is no coincidence: The high-positioned, liquid-cooled charging cable reaches the charging socket of every electric vehicle. After all, the idea is for electric vehicles from all manufacturers to be able to charge up here. A large, 10-inch touch display offers a wide variety of options for interacting with the customer. Altogether, this meticulously devised concept is intended to ensure that the customer's experience of the charging process is uncomplicated and pleasant.

The aesthetic impulse also finds expression in multiple lighting elements: A visible stripe on the front of the charging station displays the operating mode. Light units to the left and right subtly mark the borders of the charging station and define the area of the parking space.

The right juice for every electric model

As flexible as the Porsche Engineering development is in terms of the individual structure of the charging park, it is every bit as flexible with regard to the charging convenience offered to the customer. The charge control unit in the station automatically establishes the communication with the vehicle. It instantaneously compares the requirements of the vehicle with the capabilities of the charging station at the beginning of the charging procedure. If a vehicle is set up for the 800-volt technology developed by Porsche, it can be charged at high power. But the charging station from Porsche Engineering also supplies vehicles designed for lower charging power levels. They, too, receive the electricity they need.

Technologically, Porsche employs the Combined Charging System (CCS1/CCS2) as the European standard. This is adapted to the higher voltage level and higher currents of the charging park. With minor modifications to the charge control unit, however, it is also possible to implement charging standards such as CHAdeMO or GB/T, enabling service to other vehicles even in regions as far afield as Japan and China.

Reliable—now and in the future

In addition to the high degree of flexibility offered to operators and customers today, great attention was also given to ensuring the system would be able to keep up with future developments as well. For that reason, Porsche Engineering colleagues from Prague developed the software for the control of the charging park, the charging procedure and the server connection themselves. This not only makes the charging park smart-grid-capable—i.e. able to actively communicate with the infrastructure—but also makes it possible, thanks to the integrated, centralized intelligence, to continue operating even if, for example, the back-end communication to the operator's electronic payment system goes down. The charging point remains available to the customer even in such situations. Porsche Engineering set out with the objective of ensuring safe, convenient and fast charging in every situation. Thanks to this unwavering focus on the customer, and the intelligent design, the new charging infrastructure from Porsche Engineering provides the optimal solution for practically every operator.

3

800 V

The new charging station generation is designed for 800-volt technology. But it is also downward-compatible for all vehicles on the market with 400-volt technology.

10 inches

The big touch display is designed to enable optimal readability even with direct sunlight.

320 kW

CCS

Porsche uses the Combined Charging System as the Europe-wide standard. But CHAdeMO and GB/T will be implemented later as well.

20 min

The battery of the Mission E is ready for the next 400 kilometers within 20 minutes.

Charging parks with attractive architecture: The concept of the innovative charging park from Porsche Engineering enables cars to charge up for a range of some 400 kilometers in just 20 minutes. Thanks to intelligent technology, elegant design and simple payment options, the system offers customers a premium charging experience. But what really makes the fast-charging parks from Porsche Engineering special is that by working more efficiently, operators can expect significantly lower operating costs. Faster, more flexible and more efficient: a typical Porsche solution, in other words.

Electromobility as an opportunity

Interview: Hans Schilder
Photos: Heiko Simayer

Porsche is actively pursuing the future of electromobility—both by building high-performance sports cars with electric drive technology and by developing a fast-charging infrastructure that is more efficient and customer-friendly than conventional charging systems. Where the journey is going and where challenges await is discussed in this interview with Otmar Bitsche, Director of Development Electrics, Electronics, Electromobility at Porsche and Michael Kiefer, Director of High-Voltage Systems at Porsche Engineering.

M.K.— Michael Kiefer
O.B.— Otmar Bitsche

Carmakers never bothered with the issue of fuel supply for combustion engines; they just left it up to the oil companies. Why has Porsche Engineering decided to develop its own charging park for electric cars?

M.K.— With the transition from combustion engines to electric drive units, I have to bring my customers along on a journey into the new electric world. With our brand, 100 percent of our customers are accustomed to combustion engines. So I'm confronted with a chicken-and-egg question. No charging network, no electric vehicles. And if there are no electric vehicles, no one will invest in a charging network. So we can only sell electric cars if we give customers the security of knowing that there is a viable charging network available. Porsche is therefore forging ahead and actively pushing the expansion of the charging infrastructure itself.

How are you doing that?

M.K.— For one thing, we are providing the market with an efficient solution, while at the same time the Volkswagen Group is participating in the "Ionity" joint venture for the expansion of a fast-charging network along the European highways. Once there are enough electric vehicles on the road, investors will undoubtedly jump on the bandwagon with charging stations and make a business case out of it with which they can make money. But to make this business model possible, we need a burst of initiative like our own efforts to make the overall concept viable in the first place.

How important is a user-friendly charging system?

O.B.— Very important. The current system with complicated payment modalities and extremely variable energy prices is a real barrier to the acceptance of electromobility.

„With the charging infrastructure developed by Porsche Engineering, the customer needs just a single charging card that is accepted everywhere.“

Michael Kiefer,
Porsche Engineering

Thinking ahead: Michael Kiefer (top) and Otmar Bitsche (bottom) live out electro-mobility in their daily lives, unsurprisingly enough, and are conributing to driving forward the expansion of a European charging infrastructure.

Michael Kiefer. Director of High-Voltage Systems at Porsche Engineering Group GmbH ▪ Born in: 1975 ▪ Grew up: Near Karlsruhe ▪ Career: Technology and Business Studies, University of Karlsruhe ▪ 2002 Trainee AUDI AG, 2006 Porsche, with Porsche Engineering since 2016 ▪ Family: married, two children ▪ As the Director of High-Voltage Systems at Porsche Engineering, Michael Kiefer has developed a highly flexible and inexpensive fast-charging station with 350 kW of DC charging capacity whose different modules allow it to adapt to every location and need.

Otmar Bitsche. Director of Development Electrics, Electronics, Electromobility at Porsche ▪ Born in: 1957 ▪ Grew up: Feldkirch Tosters ▪ Secondary school: Feldkirch Gymnasium ▪ Career: Electrical Engineering studies at TU Graz ▪ 1990 Steyr-Daimler-Puch, 1996 Smart, 1997-2012 Mercedes, now Porsche ▪ Family: married, one daughter ▪ Otmar Bitsche is the director of the E-Mobility field at Porsche AG. Today he is responsible for the development of electric cars for the sports car manufacturer.

M.K.— Someone who wants to drive from Munich to Hamburg in an electric vehicle today needs multiple cards with which they have to authenticate themselves at the charging stations. Porsche eliminates this authentication rigmarole for customers by establishing contracts with all of the charging station operators, so the customer only needs one charging card that is accepted everywhere. And they can also count on a guaranteed electricity price that applies throughout the entire country. Customers of the Porsche charging service ultimately receive just one transparent bill from Porsche.

What distinguishes the charging park from Porsche Engineering from other charging station concepts?

M.K.— We have approached the charging park issue from the perspective of the customers who have to operate the charging stations. But also from the perspective of the operators who have to build these parks. For both, the market has few optimal solutions to offer. Their use is often complex or there are difficulties with the maintenance, servicing or diagnosis capabilities for such parks. So we have invested a great deal of effort in the issue of user-friendliness. Our charging stations even look different than the predominant ones seen today. They aid the customer through a design that guides the cable cleanly. We've also designed the overall system for the lowest possible power loss. That pay-off in terms of operating costs and the potential operator of the park stands to save a lot of money.

800 Volts
of DC fast charging are offered by the Porsche charging stations

20 min
is how long Porsche charging takes to achieve a range of

400 km

Can the Porsche charging park be built in any location?

M.K.— We have two different variants, the charging park and the ChargeBox. The park is designed for locations with more available space in which a very high volume of charges is to be expected, 24 hours a day, seven days a week. With a small compact station, however, a charging park is possible in the city as well, for example in a residential area. For all areas with extreme space constraints, there is our second variant, the ChargeBox with an integrate battery. It can be connected to the normal low-voltage grid and enables fast charging in spite of its compact dimensions.

Is fast charging always the goal for Porsche?

M.K.— Yes. Our power range starts at about 150 kilowatts today and extends up to 350 kilowatts. In a later phase of development, it could be even more than that. We believe that everything that will be installed in the future will play out in this power range. In the public space, no one wants to have long-term parkers at the charging stations because charging takes so long. Low charging capacity is really only acceptable for charging at home.

The Porsche charging stations enable direct current fast charging with 800 volts. Can this be used by all electric cars currently on the market? What prerequisites do they have to fulfill for fast charging?

O.B.— Most electric cars can be charged with 50 kilowatts today, but not more.

M.K.— So future charging points will have to be free of discrimination. What that means is that all fast-charging stations, even if they offer 350 kilowatts, will have to be able to charge all electric cars on the market.

Porsche fast-charging station: Its design is futuristic and practical at once: Michael Kiefer (right) demonstrates the convenient operation to Otmar Bitsche. On the left, you can see the battery of the Mission E and on the right the ChargeBox from Porsche Engineering.

Is inductive charging part of your future plans?

O.B.— On the vehicle side, absolutely. We plan to offer inductive charging later with the Mission E as well. But that does not allow fast charging. However, with this technology a vehicle can be charged in one's own garage overnight with little complication. The dilemma with inductive charging is simply that there is not yet a binding standard in place. That is the objective of a joint research project with other manufacturers.

M.K.— The lack of a standard is currently standing in the way of public charging spots as well. Today there would have to be a dedicated induction charging spot for each manufacturer, and that is an entirely unattractive model for the operators of parking garages.

O.B.— With standardization it's not just about the transmission of power; all the safety and communication pathways have to be standardized as well. Foreign object recognition, living object recognition, metal object recognition, the entire communication apparatus and even the positioning of the car all have to be standardized.

When will this standard emerge?

O.B.— With all the bells and whistles I think not before 2020. Perhaps we'll manage to standardize power transmission by mid-2018.

What type of electric motor is a possibility for Porsche sports cars—asynchronous, synchronous or permanent magnet motors—and why?

O.B.— Permanent magnet synchronous motors are our choice. That is primarily due to three reasons. First: impressive power-to-weight ratio, i.e. a low weight with high output, because the excitation is provided by the permanent magnets. Second: very high torque. Third: sustained high performance is possible.

Is Porsche committed to the dual motor concept—with one motor on each of the axles?

O.B.— At the moment we are deliberately focusing on all-wheel technology. But other concepts are possible as well.

Currently high-voltage batteries using the latest lithium-ion technology are the gold standard. They offer an energy density of currently about 180 watt hours per kilogram. Are there battery concepts for the future that envision a significantly higher energy density?

O.B.— We expect an increase in energy content of roughly five percent per year. There's a bit of hype surrounding the solid state electrolyte technology at the moment. We see major technical challenges there, but we're watching it very closely. The lithium-ion technology definitely has a lot more potential through ceramic separators, through silicon dioxide, through electrolytes, etc.

Does fast charging damage the battery?

O.B.— Not when it's done properly. However, it's not possible to get a 100 % charge with fast charging. As the charge level rises, the power has to be cut back. Altogether, we can charge for 400 kilometers in as little as 20 minutes without the battery suffering. That makes the charging experience very pleasant for the driver, because the vehicle controls the charging completely automatically.

M.K.— Whether on the vehicle or infrastructure side, we will offer the users of our systems a fast, flexible and efficient solution.

The CCS (Combined Charging System) plug: It complements the type 2 connector used as the standard in Europe with two additional power contacts and a fast-charging function and supports AC and DC (alternating current and direct current) charging with up to 170 kW.

"We will offer inductive charging with the Mission E shortly after the market launch. But we still lack a binding standard for it."

Otmar Bitsche, Porsche

400 volts

and three-phase current with at least 11 kilowatts and 16 ampère should be provided by a wallbox.

Almost

8,000

charging stations for electric cars existed in Germany at the end of 2017.

Creative engineering prospects impress

Text: Hans Schilder
Photos: Liana Haitonic

Extraordinary imagination was shown by the participants of the Porsche Engineering Student Competition 2017, which was held by Porsche Engineering in cooperation with the Technical University of Cluj-Napoca in Romania. The engineering prospects used inexpensive standard parts to build and program cars that drive autonomously, taking on the challenge of a very exciting competition.

The day of competition had arrived: The young students focused intently on the floor of the brightly lit hall. There, black lines just a bit wider than a human foot mark out two oval test tracks on which the entrants' model cars were to travel completely autonomously using electronic control systems developed and programmed by the students. This was the assignment facing entrants in the Porsche Engineering Student Competition 2017.

The competition was organized by Porsche Engineering in cooperation with the Technical University of Cluj-Napoca and open to teams of students enrolled in engineering at an accredited Romanian university. The objective of the event was to bring the current topic of "autonomous driving" to the student level with a challenging, yet playful scenario. And as an added bonus, the most successful participants would receive special support from Porsche Engineering.

"Cluj, Romania, is the ideal place for it", says Holger Dinkelaker, Porsche Engineering's point man for the competition. "Cluj and its university are leaders in the field of software, a sort of European Silicon Valley. It's a good fit with our growth strategy, particularly as regards software."

Outstanding prospects: John Heldreth (right) explains the rules of the competition to the competitors and tells of the opportunity for close collaboration with Porsche Engineering that awaits the winners. Holger Dinkelaker (left) gives the start signal.

A total of 27 teams applied; of that pool, the seven most promising four-person teams were ultimately invited to take part in the competition. All of the entrants were students between their second and fourth semesters and between 19 and 23 years of age.

To ensure fair conditions, Porsche provided each of the teams the same 147 standard components with which to build their competition vehicles. This included the chassis, axles, electric motor and other components from which a model car in the conventional 1:18-scale can be built. Also uniform: the electronic control components, including the credit card-sized, programmable mini-computer Raspberry Pi 1 as the 25-Euro heart of the operation; the programmable microcontroller Arduino Mega 2560 1 to control the hardware; and other equipment, including an ethernet shield; laser, light and ultrasound sensors; cables and batteries. More expensive equipment owned by the participants was prohibited to ensure that students with greater financial means did not enjoy an unfair advantage. "Ultimately it's about finding the best solutions on the same basis, with one's own creativity and ideas," says Dinkelaker.

7
teams, each with four members.

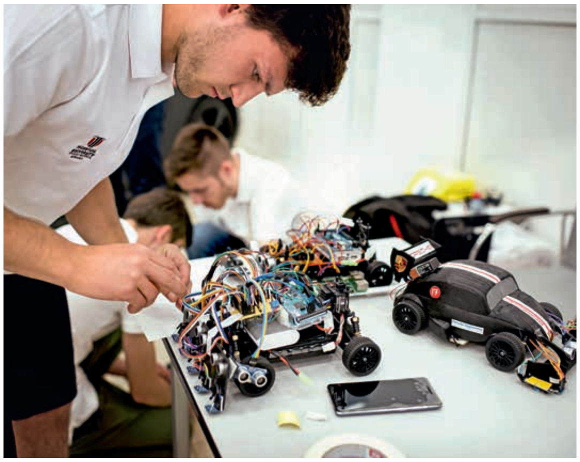
147
standard parts were available to each team for car construction.

4
weeks is all the teams had to build their cars.

3
different challenges had to be mastered by the cars on the parkour.

Cluj, Romania

Where's the error? A team discusses what last-minute improvements could still be made to the competition vehicle (left side).



Teamwork: The participants build and program their vehicles themselves. Then they send them off on the demanding obstacle course (right). An exciting moment for all involved.

2016

Porsche Engineering Romania SRL is founded.

25

scholarships per year are awarded to students at TU Cluj-Napoca by Porsche Engineering.

Cluj-Napoca is the second-largest city in Romania after the capital of Bucharest. It is located in the historic Transylvania region in the country's northwest. The Technical University of Cluj-Napoca has roughly 18,000 students and 13 faculties. One special feature is the German-language program in industrial engineering, which is offered in collaboration with the University of Stuttgart. Porsche Engineering Romania is a partner of the Advanced Techniques in Automotive Engineering (ATAE) master's program, in which 25 students are prepared for work in research and development in the automotive and automotive supply industry. One further manifestation of the close collaboration between Porsche Engineering and the Technical University of Cluj-Napoca is the annual Porsche Engineering Student Competition.

The teams had four weeks to build their cars, equip them with the requisite electronics and develop software with algorithms that would enable the car to perform the sophisticated tasks demanded of it. The model cars had to

- Recognize the test course and travel along it as many times as possible in the defined time without going outside of the borders of the track
- Detect and evade objects placed on the track in the same position for all participants
- Respond to moving objects in a levelheaded manner

On the final day, it immediately became evident that the light conditions presented a greater challenge for some teams than had been assumed. Some of the student-developed programs steered the competition models outside of the border lines of the track. But improvements were allowed. The teams hastily whipped out their laptops and connected them to their respective cars' mini-computers in order to correct their software on the fly beside the oval track. They did not always find a solution to their problem right away. Often, members of competing teams willingly offered useful tips. Team spirit, clearly, was more important than victory.

After an exciting final day, two teams had successfully completed all tasks. The winners were just 21 and 22 years old; their team name: "bitsplease." A short time later, they traveled to Weissach for an intensive introduction to Porsche Engineering. There they were greeted by Michael Steiner, the Board Member for Development at Porsche AG. In meeting with the young prospects, he demonstrated just how seriously the company's leadership takes the competition and its support for young talent. The participants will be able to draw on the support Porsche in the future as well, looking forward to work-study opportunities, internships and support with academic theses.

The successful Student Competition will take place again this year, complementing Porsche Engineering's other forms of engagement in Cluj. Porsche Engineering Romania SRL, the newest subsidiary of the globally active engineering service provider Porsche Engineering Group GmbH, is increasing its staff numbers in the areas of software development and traditional vehicle development. Through its cooperation with the Technical University of Cluj-Napoca, the company is also making a lasting contribution to the growth of the master's program in automotive technology and offers special lectures and seminars held by experts from Porsche Engineering. Moreover, the best students in the field of vehicle development also receive a scholarship.

“Cluj and its university are leaders in the field of software, a sort of European Silicon Valley. It’s a good fit with our growth strategy, particularly as regards software.”

Holger Dinkelaker,
Porsche Engineering

The director of the automotive programs at the Technical University of Cluj-Napoca, Prof. Bogdan Varga, takes an accordingly appreciative view of the effects on his institute: “The partnership with Porsche Engineering is one of the most fruitful success stories that the TU Cluj-Napoca has accomplished so far. Based on this partnership, the quality of our students is rising and the number of young employees of Porsche Engineering Romania is also growing exponentially.”

Marius Mihailovici, General Manager of Porsche Engineering Romania, regards the partnership also as a win-win situation for all three parties involved. “Students benefit from our experienced engineers, the Technical University is able to add a new master’s program to its portfolio and our company has access to highly qualified engineers who are already familiar with our work and field.”

The future of production

Text: Robert Stahlmenning
Photos: Matthias Haslauer, DMG MORI

DMG MORI is an iconic machine tool manufacturer known the world over. Porsche fans will be familiar with the distinct logo from the Le Mans race cars. The endurance race provides grounds for two global players to combine their expertise for outstanding sports performance. Christian Thönes, DMG MORI AG's CEO, believes technologies such as rapid tooling and additive manufacturing hold great potential for automobile manufacture and many other industries.

What if a component's shape didn't matter for manufacturing? What if bionic structures pointed the way to more effective design of the coolers encasing battery packs or fuel cells? What if they were twice as efficient as conventionally produced components despite being only half the size? What if these components consisted of not eighty, but of only one single part? Enduring thanks to precisely calculated and implemented load paths, a single material for recycling—perfectly fulfilling all requirements across the entire lifecycle. Promises that quicken any engineer's or technically inclined person's heart. Hardly surprising, then, that that's exactly how Christian Thönes sounds when speaking about additive manufacturing: Excited. Additive manufacturing produces new components from metal or plastic powder using the power of lasers—instead of cutting them from blocks or casting them in molds. "On the one side, the possibilities are almost limitless. We can save so much weight, optimize functionality, make completely customized components. On the other side, productivity still presents a major challenge".

DMG MORI has successfully marketed laser deposition welding using powder nozzles since 2013. Its acquisition of Realizer in 2017 expanded its portfolio to include the powder-bed process, a method today already accounting for eighty percent market share in the metals industry worldwide. "What's so great about it is that even batch sizes of only 1 are economically viable. Fast and fully customized", says the 45-year-old who has led DMG MORI AG since 2016. This means that tailored solutions are possible at any time—which is especially important in testing and prototype construction. Whenever you can produce a part with additive manufacturing, you eliminate tool development and thus save time and money. The new production methods allow manufacturing even complex assemblies quickly and with 100-percent reproducibility. In and of itself, the process already considerably increases effectiveness but it doesn't stop there. The components themselves contribute further to effectiveness as they can be designed free of the constraints imposed by production requirements. How about a hollow shaft with internal ribbing to save material and thus weight, for example? Impossible to produce purely through machining, difficult to produce through a combination of machining and cutting—and even then, you'd likely need several constituent parts. With additive manufacturing, the hollow shaft can be made of any material, have any shape, no problem.

Use material only where it supports load paths—sounds simple and is very clever. This approach follows nature's example and uses focused light as a tool. Which is effective and, sometimes, has amusing side-effects. "One of our customers wanted us to remove the viewports on the build chamber", Thönes relates, "because the workers were always standing by the machine and staring mesmerized at the build process". Watching a laser dart across the powder bed like a humming bird, burning shapes into the metal and setting off a miniature fireworks display. The process of creating a high-efficiency component is as fascinating as the result itself, it would seem.

DMG MORI is the only supplier worldwide offering full solutions for both additive manufacturing techniques: In the powder-nozzle method, also referred to as direct energy deposition, metal powder rides a gas stream to the nozzle. Laser and powder nozzle target the same point. Next, melting. For the powder-bed method, also called selective laser melting or SLM, a laser melts down metal powder. While powder nozzles employ a machining tool with five-way motion paths to produce volume, SLM lays down layers to grow the component only along the z-axis, that is upward. The separate layers are each no more than 20 to 100 µm thick. Geometrically regular lattice structures or honeycombs are merely warm-up flexing. Almost any imaginable shape is possible, totally ignoring the constraints of conventional production methods.

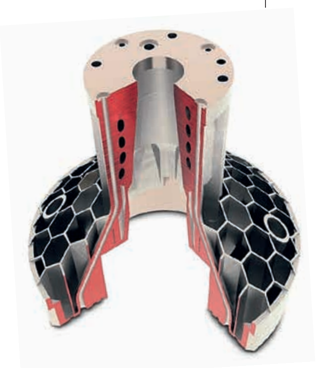
Airplane construction, surgical equipment, dentistry or automobiles: "Everyone needs to make their components lighter", the CEO says. "That's how the automobile manufacturers manage to cut fuel consumption and carbon emissions". Additive manufacturing is the key to sustainable success.

The new technology often makes it easier to combine different materials with one another. "Focused laser power producing several thousand degrees Celsius can fuse stainless steel and Inconel, for example", Thönes explains. You can also create graduated materials that transition smoothly into one another, something that conventional methods can achieve with only considerable difficulty, if at all.

Additive manufacturing technology supplements classic production techniques.

Christian Thönes remains adamantly convinced, however: "Despite all the benefits additive manufacturing brings to the table, traditional production methods like machining and cutting will remain with us in future". The traditional will join with the novel. Precision at dimensions smaller than 0.1 mm will still be provided by classic, high-precision machining tools, meaning that new production techniques like additive manufacturing will supplement existing technology. DMG MORI is a full-liner—both in the field of cutting machining as well as in the field of additive manufacturing using powder nozzles and powder beds.

The fact that additive manufacturing is an economically viable solution even at batch sizes of 1 is proof that the method is a keystone of tomorrow's factories. The new type of production will become the physical extension of digitization. Thönes explains: "It makes the engineers' ideas material truth and allows the optimized designs from the digital world, CAX systems, to be built". These ideas find expression in a digital environment that DMG MORI is continuously expanding. The caption: "Path of Digitization". DMG MORI uses CELOS, an app-based control system and user interface, as well as ADAMOS to cover the entire process chain on the digital side. ADAMOS stands for Adaptive Manufacturing Open Solutions, and is an open digital platform created by DMG MORI in 2017 in collaboration with Dürr, Software AG, Zeiss and other partners. "We want to establish an international standard—from machine manufacturers for machine manufacturers, their suppliers and customers", Christian Thönes quotes ADAMOS's declared goal. New partners? Are always welcome!



Complex geometries: DMG MORI produces the latest generation of powder nozzle holders using additive manufacturing. Production without tools reduces costs, cuts production time and offers considerable benefits. Complex geometries become possible, component weight is 70 % lower, 22 components are merged into a single one and cooling performance becomes greater thanks to the larger surface area.

Christian Thönes was born May 1, 1972. He is married with three children. He studied business administration in Münster, Germany. He was head of marketing at what was then Gildemeister Aktiengesellschaft, developed the Advanced Technologies (Ultrasonic and Lasertec) business field, and was Managing Director of DECKEL MAHO in Pfronten, Germany. Thönes was appointed Head of Development and Production in 2012 and today is DMG MORI AG's CEO.

Making light

Text: Thorsten Elbrigmann
Photos: Porsche AG, Rafael Krötz

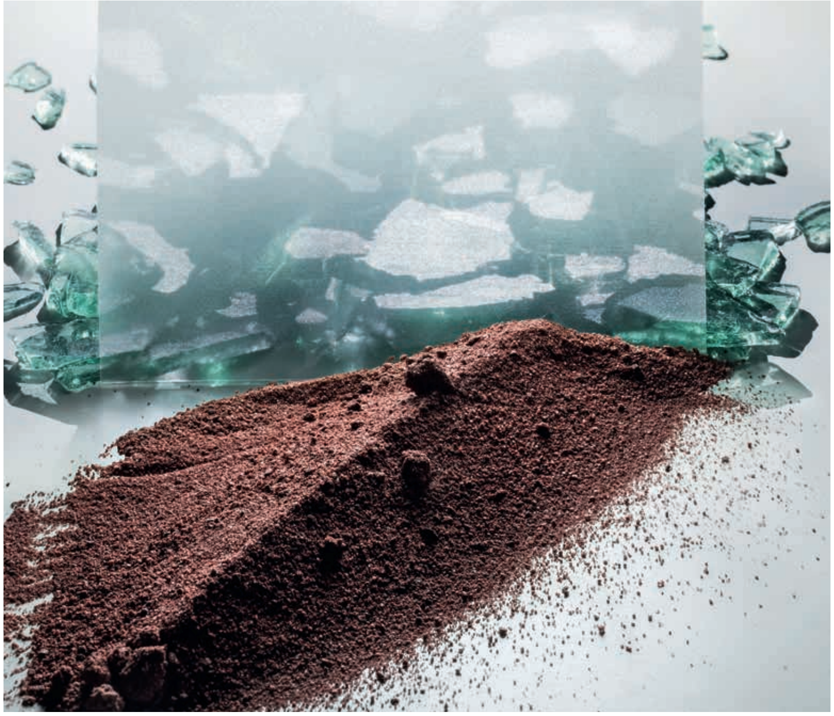
Nothing improves efficiency more than cutting weight. But the road to lightweight design is a stony one. Time then, perhaps, to change course and venture forth upon paths untrodden. By checking our smartphones, no less, as evidenced by the new Porsche 911 GT3 RS.

Besides new manufacturing methods, innovative materials play an increasingly important part in automobile construction. In the interplay between high-strength steel, deep-drawn sheet steel, light alloys and plastics, we seek resistance to temperature fluctuation, enduring toughness, the capacity to absorb loads in a crash and material purity for recycling after replacements. The materials are further expected to throw their (light) weight into improving the efficiency of the overall vehicle.

Researching improvements for existing materials is no longer sufficient if these requirements are to be met. We need to think outside of the box and see what's going on in other fields. At Porsche, glass technology has been receiving a lot of attention in recent years. The desire to make heavy glazing lighter is by no means new. Motor racing has in the past substituted it with plastic, for instance with *Makrolon®*. However, the material's low resistance to scratching and its less-than-optimal visual characteristics prohibit it from use in mass-produced road cars. This is why the engineers have been looking into the matter of thin-film glass. The material, which became known as *Gorilla Glass*, is used to manufacture monitor screens. Tablet PCs, flat-screen TVs, and smartphones have been using it for years. Its benefits: ideal visual characteristics, low weight, very high strength. Porsche first used glazing of comparable quality for the laminated glass in the rear window of the Porsche 918 Spyder with Weissach package. The roughly 20-by-20-centimeter flat pane would have to be considered trying-on-for-size. We're thinking bigger today.

Classic material, new approach

The technology for processing thin-film glass has progressed enormously over the past three years. Engineers are now capable of realizing curved panes of thin-film glass, the first specimens of which saw the light of day in a Samsung smartphone. What we know as Gorilla Glass from smartphones is actually little more than an age-old material: glass, the same stuff made of recycled glass shards, sand, and—when it comes to car windows—a thin safety film between two layers of thin glass.



Gorilla glass: The idea for highly durable thin-layer glass comes from display design for cell phones and laptops. Porsche is the first automobile manufacturer to make use of this laminated glass, which is made of sand, recycled glass, and safety film. The thin-film glass is more stable, lighter, offers better UV protection and, in the future, may even offer display functionalities.

For glass to become thin-film glass, it first needs to undergo chemical treatment. To human perception, glass appears smooth and flat, but seen through an electron microscope, it is as jagged and fissured as a canyon. The floors of the crevasses are littered with molecules. A chemical treatment draws them out and replaces them with larger molecules that cram into the gap and thus increase material density at surface level. This increases the glass's compressive stress and makes it extremely strong. Tests have shown that a thin-film glass windshield with a 2.1-millimeter exterior layer and a 0.55-millimeter interior layer combined with PVB safety film is at least 200 percent stronger than a conventional compound glass windshield. Such a windshield would be substantially more resistant to hail and stone chipping, be far more impervious to scratching, and break only at much higher loads in a crash. Add to this the fact that thin-film glass possesses a degree of flexibility and is thus capable of enduring more body torsion.

Lighter, yes. And quieter, too.

The weight saved is enormous. The conventional single-layer safety glass version of the current Porsche 911's rear window, for example, weighs

40%
lower weight,

200%
stronger,

blocking
99%
of UV radiation.

The 911 GT3 RS's side window: The high-strength curved side window in the Porsche 911 GT3 RS—shown here in its prototype form—not only improves the power-to-weight ratio but also blocks out wind noise.

Weissach package:
For those most dedicated of drivers, the Porsche motorsports department has put together the optional Weissach package that cuts weight even further. It comprises an even greater number of carbon components in the chassis, interior, and bodywork and includes an option for magnesium wheels. In its lightest configuration, the 911 GT3 RS weighs only

1,430 kg

Porsche 911 GT3 RS

CO_2 emissions (combined): 291 g/km
Consumption urban: 19.2 l/100 km
Extra-urban: 9.0 l/100 km
Combined: 12.8 l/100 km
Efficiency class: Germany: G
Switzerland: G

5.8 kilograms. The same window made of thin-film glass weighs only 3.7 kilograms, cutting the weight by about forty percent. And that's only one component. At present, Porsche uses this glazing on the Porsche 911 GT3 RS, whose rear window and rear side windows are made of it. But it gets even better. The new compound glass offers greater UV protection. In this case, however, we have the safety film to thank for blocking 99 percent of the UV radiation. Conventional single-layer safety glass without the film blocks only around seventy percent. The high optical quality of thin-film glass considerably reduces the perceptible distortion familiar from thicker glazing, especially at the low slope of the installation angle. On top of that, the glass also thaws out much quicker in frosty weather, simply because it is thinner. With a view to electric mobility, we find yet another benefit in the greater damping effect on high-frequency sound waves.

Drawbacks? There are some, but not many. Presently, production is still expensive, not least because the automotive industry is only a minor customer for those manufacturers dealing in this quality of glass. Primary demand arises from displays for consumer electronics. There's also as yet no solution to the glazing's greater flexibility preventing it from use as a lowerable door window: At higher speeds, the air stream would bend the glass outward and impede closing. For the mid-term, the plan is to use a hybrid composition using the chemically compressed thin glass only for the interior side of a compound glass pane.

More glass in the passenger compartment?

Right now, Porsche is investigating improved infrared reflection. Current levels match that of familiar glazing types, but the aim is to enhance functionality to achieve higher heat insulation. Thin-film glass could also revolutionize surface design in the passenger compartment. Radically new controls in the form of curved, touch-panel displays could offer drivers a means of completely customizing all controls to suit their personal preferences. One vision doing the rounds: Drivers save their custom passenger compartment configurations on *My Porsche* and thus get their own, entirely personalized control interface in any Porsche they drive.

Over time, thin-film glass of various properties will replace glazing in more and more walks of life. The benefits are evident. Besides greater strength at lower weight, the much higher sound insulation will make thin-film glass the go-to choice for electric mobility in the automotive industry.

Combined forces

Text: Thomas Fuths
Photos: Stefan Bogner

The word geyser (Icelandic spelling: geysir) is Icelandic for "set in turbulent motion." What could possibly describe Porsche boost technology more accurately? And where better to experience the forces of nature and technology than in Iceland in a Porsche Panamera 4 E-Hybrid Sport Turismo: Boosted exploration of turbulent motion.

The *Great Geyser* in Bláskógabyggð in southwestern Iceland is considered the oldest hot geothermal spring known to mankind and is the origin of the name applied to this natural phenomenon all over the world. Fueled by the heat of the Earth's core, hot water shoots high into the sky. Fire propels water from the earth to the air, an amazing convergence of the elements playing out in a single natural spectacle. The chemist Robert Bunsen was the first to scientifically investigate and explain the fascinating phenomenon. The exact same year the great scientist died—1899—was the year the Lohner-Porsche stepped onto the automotive stage. From then, it took Ferdinand Porsche only a few months to evolve the electric automobile into a hybrid vehicle.

An urge to explore has always helped humanity unravel the world's secrets. It is the urge to explore that drives us onwards—and sometimes takes us back, too: Purely in terms of locale, on a long journey to Iceland. Back to the Great Geyser in a vehicle that forms energies into turbulent motion, into propulsion you can measure, propulsion produced in a Porsche by exceptional boost technology that brings Porsche's sports car ideal to the world of hybrid vehicles.

Porsche 918 Spyder—a pioneer

Electrification of the drivetrain is one of the automotive industry's most significant undertakings and also one of the greatest challenges of the twenty-first century. The goal here is not to replace the combustion engine with electric motors overnight. For Porsche, the declared goal is instead to smoothly transition to a new era. In 2013, the Porsche 918 Spyder demonstrated what happens when combustion engines meet electric drives: Engine and electric motor conjoin in a new alliance of efficiency and dynamism. The electric motors supply the capacity to drive, at least for a time, without producing any emissions—but they also act as a booster for supercharging, again at absolutely zero emissions. Turbo-charged engines and electric motors combine to create an entirely new form of dynamism. Porsche has now applied this drive concept—the Porsche 918 Spyder's hybrid strategy—to the latest Panamera generation. Porsche is for the first time offering an alternative body version of the Panamera as a plug-in hybrid: The Panamera Sport Turismo. The vehicle embodies a progressive concept combining two motive forces: Fossil fuels, available anywhere in the world for quick and easy refueling, and the inexhaustible, endless supply of renewable energies in the form of wind, water, sun and geothermal power. And nowhere on Earth has the latter been more thoroughly harnessed than in Iceland.

We took the five-seater Panamera 4 E-Hybrid Sport Turismo on a tour all around the island along the more than 1,300 kilometers of Iceland's Ring Road. Before heading off, we charged the lithium-ion battery (energy capacity 14 kWh) from one of Iceland's five major geothermal power plants. Energy that is simply available. Energy that the Panamera converts to propulsion without emitting any carbon. In E-Mode, on electric power alone, the new Sport Turismo reaches up to 140 kilometers per hour. When combining both drives, the Porsche reaches Iceland's highest speed limit of 90 kilometers per hour in under four-and-a-half seconds. On the motorways in its home country, or on race circuits, the car will move at up to 275 kilometers per hour.

Full boost from the word go

As noted, Porsche is employing the 918 Spyder's hybrid strategy in the Panamera 4 E-Hybrid Sport Turismo. Just like in the super sports car, the Sport Turismo's electric motor immediately supplies its full electric power—100 kW (136 hp) and 400 Nm—upon a tap of the accelerator or E-pedal. In the model's first generation of plug-in hybrid, the Panamera S E-Hybrid, you needed to depress the accelerator beyond 80 percent of its pedal travel to activate the e-drive's extra boost. Now, the electric motor and the petrol engine play the same league right from the start, with the electric motor supplying additional drive power all the time. Together with the power stats of the V6 biturbo engine (243 kW/330 hp/450 Nm), you get a boost scenario combining the electric motor and two turbochargers. The Panamera 4 E-Hybrid Sport Turismo also uses the electric energy to raise its top speed. This new kind of E-Performance—more power, more driving fun, lower fuel consumption, periods of zero emissions—is regarded as the boost concept of tomorrow.

Together with the disengager coupling connecting it to the V6 petrol engine, the electric motor presents a new generation of Porsche hybrid module. Unlike the electro-hydraulic system used in its predecessor, the new Panamera 4 E-Hybrid Sport Turismo operates its disengager electromechanically by way of an electric clutch actuator (ECA). This reduces response times even further. As in all next-generation Panamera models, power is transmitted to the all-wheel drive through a rapid-action, 8-speed Porsche dual-clutch transmission. The transmission replaces the predecessor's 8-speed automatic torque converter.

140 km/h

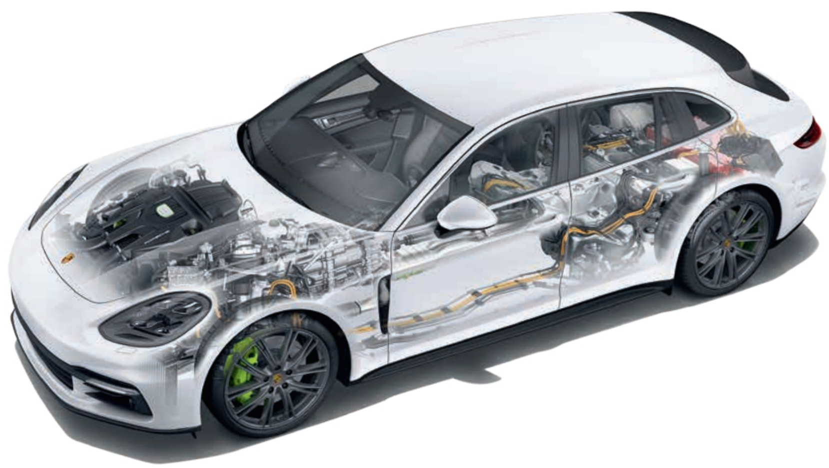
is the speed the Panamera can reach under purely electric power.

2.4 h

is how long charging takes with a 230-volt, 32-ampere, 7.2 kW charger.

14.1 kWh

is the battery capacity in the new Panamera hybrid.



Even distribution: The electric motor system is primarily grouped around the rear axle, with the front-mounted V6 combustion engine adding to the Sport Tourer's thrust.

The electric motor is powered by the lithium-ion battery, which features a liquid cooling system. Despite a 49-percent raise of energy capacity from 9.4 to 14.1 kWh, the battery still weighs the same and fits snugly into the vehicle's rear end.

What performance would you expect from a hybrid sports car's cockpit?

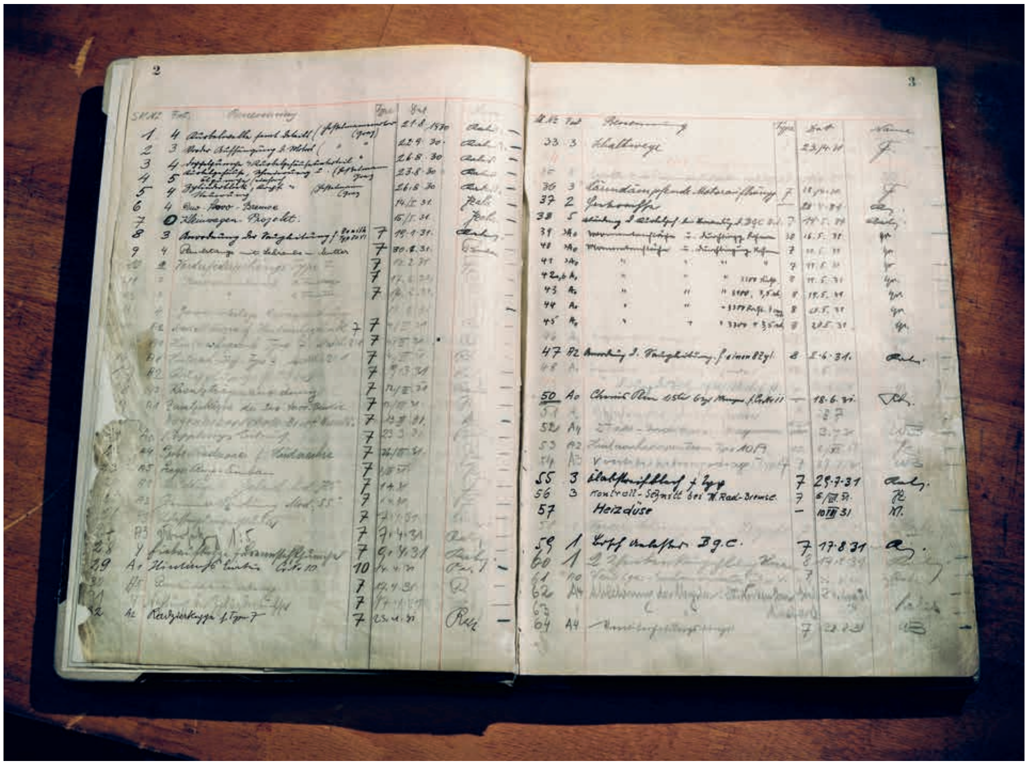
With its display and control concept, the Porsche Panamera Sport Turismo features another highlight that connects closely with the drive system: It comes as standard with Porsche Advanced Cockpit, including touch panels and fully customisable displays. Two seven-inch screens form the interactive cockpit. The Panamera 4 E-Hybrid Sport Turismo distinguishes itself from its sister models through the power meter, designed for use in hybrid mode. As a nod to the Porsche 918 Spyder, the hybrid-specific displays function in the same way as they do in the super sports car. The power meter, for example, supplies data on the electric energy currently being consumed or recovered through recuperation.

By day's end in Iceland, the all-wheel-drive Panamera 4 E-Hybrid Sport Turismo returns to one of the many public chargers. Average consumption in the New European Driving Cycle (NEDC): combined 2.6 l/100km and 15.9 kWh/100 km. If the Porsche uses the optional 7.2 kW on-board charger and a 230 V source with 32 amperes (A), the high-voltage battery takes 2.4 hours to "top up" with geothermal energy. The standard 3.6 kW charger and a conventional 320 V source with 10 A takes 6 hours for a full recharge.

After that, the Porsche hybrid is ready to once more set driver and passengers in turbulent motion. Or to take them on an entirely silent approach to the Great Geyser to be awed, just as Robert Bunsen was, by nature's eternal power.

Porsche Panamera 4 E-Hybrid Sport Turismo

CO_2 emissions: 59 g/km;
Combined fuel consumption: 2.6 l/100 km;
Combined electricity consumption: 15.9 kWh/100 km



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1931

The ledger contains the very first orders of the Porsche design office—including the first design by apprentice Ferry Porsche.

Before Porsche became the car brand that, today, is known to every schoolchild the world over, Porsche was already an established engineering firm—the roots of a global company that persist even today in Porsche Engineering. The history of the Porsche company got its start even before it officially began. When "Dr. Ing. h.c. F. Porsche GmbH" was entered in the commercial register on April 25, 1931, the independent Porsche design office had been in existence for three-quarters of a year. The first entry in the company's ledger was dated August 21, 1930. Above the first job for the Porsche engineering firm—then still provisionally headquartered in St. Ulrich bei Steyr, Austria—under order number 1 the ledger contains a technical drawing in format 4: "Crankshaft with details" for a "Hesselmann engine" for a company based in Graz, Austria. The concept of this medium-pressure engine based on the patent held by Swede Knut Hesselman is comprised of a hybrid of a diesel engine and gasoline engine—a multifuel engine whose technical implementation Porsche was now advancing on behalf of its first customer. Innovative from the first. The topic of overall vehicle development made its appearance in the ledger shortly thereafter: Job number 7 was noted with the keyword "small vehicle project." The Volkswagen was already casting its shadow into the future. But the "Type 7" was still a concept for the Wanderer brand, one of the four rings of Auto Union.

For company historians, this first ledger is the most important source on the early history of the company—and the man behind it. On January 30, 1931, just three months before the company's official registration in Stuttgart, a new signature—"Porsche"—made its first appearance in the ledger. Under Number 9, apprentice Ferry Porsche noted the following in the youthful penmanship of the then 21-year-old: "Piston rod with screw and nut."

The four ledgers that now reside in the climate-controlled safe in the Historical Archive of Porsche AG record for posterity some 300 projects between 1930 and 1945. Among the illustrious works listed in their pages are the Type 22, the successful 16-cylinder race car from Auto Union, and of course the Type 356 "No. 1 Roadster," conceived by former apprentice Ferry Porsche. The 356 became the first Porsche in history to received its official registration on June 8, 1948—exactly 70 years ago. An anniversary that Porsche is celebrating around the world. And one that would not have come to be without the engineering spirit of Ferdinand Porsche.

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