Porsche Engineering
MAGAZINE

PORSCHE UP CLOSE Porsche 718 Boxster—two generations, one idea
CUSTOMERS & MARKETS On a test drive with Porsche Engineering
ENGINEERING INSIGHTS Optimized variable valve drive—from the concept to series approval

ISSUE 1/2016

www.porsche-engineering.com

e-technology

Dirk Lappe and Malte Radmann,
Managing Directors of Porsche Engineering

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 engineering services by Porsche. We renew our commitment to that example with each new project that we carry out for our customers.

The scope of services provided by Porsche Engineering ranges from the design of individual components to the planning and execution of complete vehicle developments, and is also transferred to other sectors beyond the automotive industry.

Dear Readers,

Mission E displays Porsche's vision of electromobility—a form of electromobility that serves everyday life more smoothly while simultaneously moving beyond previous limits. How are we achieving this? By further developing and combining existing technologies, functions and components in intelligent ways. We call this "e-technology."

For example, how would you like to charge your car's battery in just 15 minutes to 80% of its capacity, or a range of 400 kilometers? This is possible with 800-volt charging systems. Or what do you think about the use of precision simulation models in development work on electric drivetrains in order to make them more efficient? The field of engineering stays on top of all these changes—from the first innovative ideas to the final products. While ensuring such matters as optimal electromagnetic compatibility for increasingly high levels of power flow.

Where is all of this leading? To a sustainable future—every bit in keeping with our long and varied tradition of customer, research and vehicle projects that never cease to work toward this aim. From Ferdinand Porsche's fully hybrid "Semper Vivus" concept in 1900 to fully electric research Boxsters and hybrid production cars—and now also the Mission E, a unique vision of what e-technology means.

We hope you find it interesting and enjoy the read!

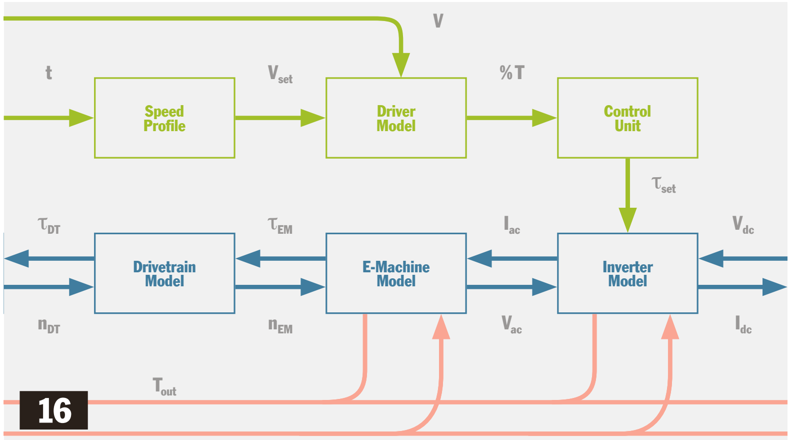
Sincerely,
Malte Radmann and Dirk Lappe

30

CUSTOMERS & MARKETS

100% TESTING

Testing services offered by Porsche Engineering combine unique resources like the Nardò Technical Center in southern Italy with expertise and experience from sports car series development. Join us on a test drive.



718 BOXSTER/718 BOXSTER S
Fuel consumption (combined): 8.1–6.9 l/100 km
CO_2 emissions (combined): 184–158 g/km

News

FRICTION MEASUREMENTS ON FULL ENGINES

ADDITIONAL TEST BENCH AVAILABLE

Porsche Engineering is expanding its testing options for engine assemblies with the addition of friction measurements and drag assessments for full engines. Strip measurements can now be used to perform targeted friction assessments for individual engine components and assemblies. As is standard in the industry, cooling water, engine oil and ambient air can all be conditioned. In addition to friction measurements for full engines, the friction potential for individual assemblies such as those of the crank drive or accessory drives should also be determined in relation to fuel consumption. The new test bench is therefore a superb addition to existing systems for testing cylinder heads and valve drives. ■

News

CAREER GUIDANCE FOR YOUNG PEOPLE

LARGE NUMBER OF POSSIBILITIES

To give young people an idea of the automotive industry and the occupational profile of an engineer, Porsche Engineering not only offers internships to high school students but is also active in a number of campaigns and initiatives. For example, the company is a regular participant in the Germany-wide "Girls' Day" campaign, which seeks to raise awareness and interest among girls in careers in science and technology. Another initiative is the "Student-Engineer Academy" (SIA), which provides specific information to high school students on how to start a career in engineering. Since 2010 the company has also engaged in a partnership with the Ellental college-prep schools in the town of Bietigheim-Bissingen. ■

BENEFIT RUN IN SOUTHERN ITALY

NARDÒ IS MAIN SPONSOR

The Nardò Technical Center (NTC) has been the main sponsor of a benefit run on the southern Italian peninsula of Salento for three years in a row now. The event is organized annually by the Rotary Club in Gallipoli in cooperation with two local running clubs. The proceeds are donated to the pediatric oncology department of the Vito Fazzi Hospital in Lecce. The run on May 22, 2016 took place for the first time on a nature trail which led through the nearby Porto Selvaggio nature park near the NTC proving ground. ■

LECTURE SERIES AT UNIVERSITY IN PRAGUE

ENGINEERS GIVE GUEST TALKS

In order to keep abreast of cutting-edge trends and developments, Porsche Engineering has always maintained close ties to research and students. A lecture series by Porsche Engineering at the Czech Technical University in Prague gave students a chance to broaden their theoretical knowledge with experience and know-how from engineering practice. From April 18 to 22 of this year, the Porsche engineers introduced the three fields of Chassis Concept, Vehicle Package & Concept, and Body-in-White Design, and discussed current trends and technologies with the students. ■

e-technology

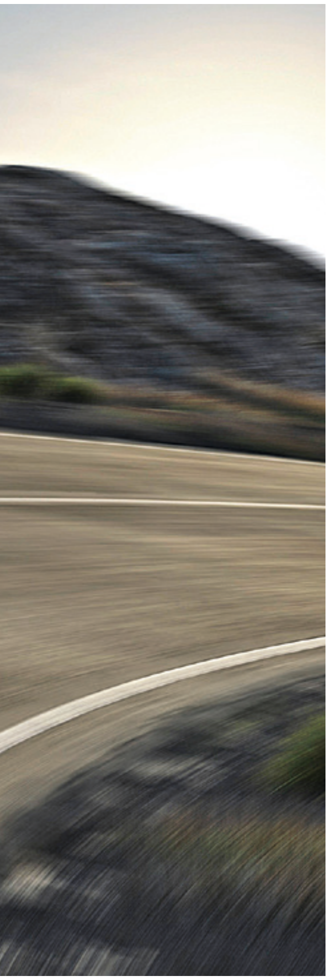
____ Intelligent further development and the linking of technologies, functions and components are making the future a reality: e-technology enables electromobility that will be more suitable for everyday use and will go beyond what is currently possible. Find out more about the potential offered by charging technology, simulation models, electromagnetic compatibility or the major trend that is digitization. The future is very promising.

e-power

New Possibilities with 800-Volt Charging

____ The broad-based breakthrough of electromobility still requires significant technical improvements with regard to day-to-day usability. In addition to further improvements in terms of costs, the range offered and the availability of an adequate infrastructure are the most critical factors. 800-volt technology shows great potential in these areas and Porsche is advancing the technology.

By Volker Reber



800-volt charging connection on the Porsche Mission E

Practical experience shows that the overwhelming majority of currently available electric vehicles is designed as commuter vehicles or for use in urban areas. In most cases, frequent recharging is necessary and the driving performance is seldom adequate to meet other user requirements. Even with long charging procedures, for example overnight or during the workday, the range that is thereby gained remains relatively small due to the current limitations in terms of battery capacity.

With the Mission E concept study presented at the 2015 IAA, Porsche offered a glimpse of a vehicle that, both in terms of performance and range, is a true Porsche and a complete alternative to vehicles with combustion engines. The efficient drivetrain and high capacity of the battery enable a range of over 500 km in the NEDC (New European Driving Cycle). This would be sufficient to handle the vast majority of all trips over a period of days with a single battery charge. The need to recharge whenever the opportunity presents itself is significantly reduced. Alternating current (AC) is used for the power supply. Conversion into the direct current (DC) required by the battery is done through a charger integrated in the vehicle. Instead of obtaining fuel at a filling station, the car is simply charged at home.

For longer trips where making good time is of the essence, long waiting times for charging procedures can make a big difference and are generally not acceptable to users. To keep the charging process brief, high charging power is required. Such alternating current charging systems are no longer suitable for use in cars due to their weight and dimensions. For this reason, rapid-charging systems in which the conversion from alternating to direct current takes place in the charging station are used. The heavy, high-current charging device is not needed in the vehicle, leaving only the requisite safety and monitoring unit. ›

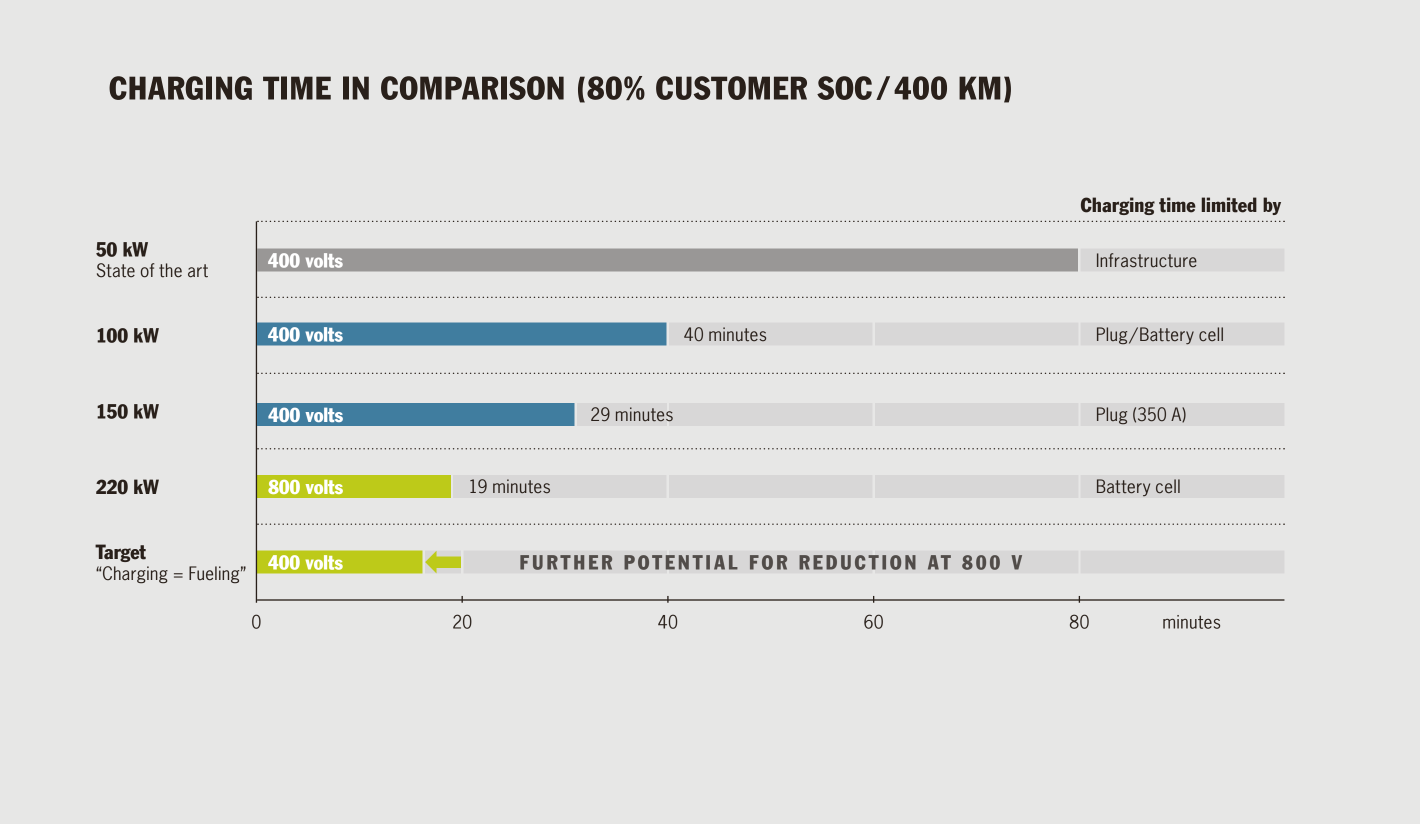


Figure 1

800-volt charging technology: Porsche turbo charging in the best time

A suitably designed rapid-charging infrastructure must be tailored to customary user behavior during long trips and offer a convenient ratio of driving time to break periods. It should be possible to get a sufficient charge for roughly 400 kilometers within the usual break time of 15 to 20 minutes. It is mainly technical factors that currently stand in the way of this objective (figure 1).

Today's DC rapid-charging stations for electric cars usually work with a voltage of around 400 volts. The charging power is roughly in the range of 50 kilowatts, meaning that the charging time for the desired 400 kilometers of range would add up to about 80 minutes. If one increases the capacity of such a 400-volt charging station, the capacity of the charging pins in the charging plug maxes out at roughly 100 kilowatts. Under these conditions, it takes about 40 minutes to transmit the energy for 400 kilometers of range. To enable further increases in terms of charging power, new cooling concepts are required. Various companies are currently working on such systems in parallel. Currently, the use of cooled charging plugs increases the charging power of 400-volt charging stations to the extent that the desired increased range can be achieved with a charging time of nearly 30 minutes.

A shift to a higher voltage is therefore inevitable in the quest to achieve charging times in the desired corridor. This is derived from the formula for electrical energy $E = U \times I \times t$, where U is the voltage, I the current and t the time. The charging time $t = E / (U \times I)$ can thus be achieved with a constant current I by increasing voltage U. By switching to a two-fold higher voltage of approximately 800 volts, the charging time can theoretically be reduced to about 15 minutes with the same electrical load on the charging pins. If one takes into account the paying process, the goal of "charging like filling up" is thus nearly within reach. Porsche has introduced its pioneering development work on this concept as Porsche Turbo Charging.

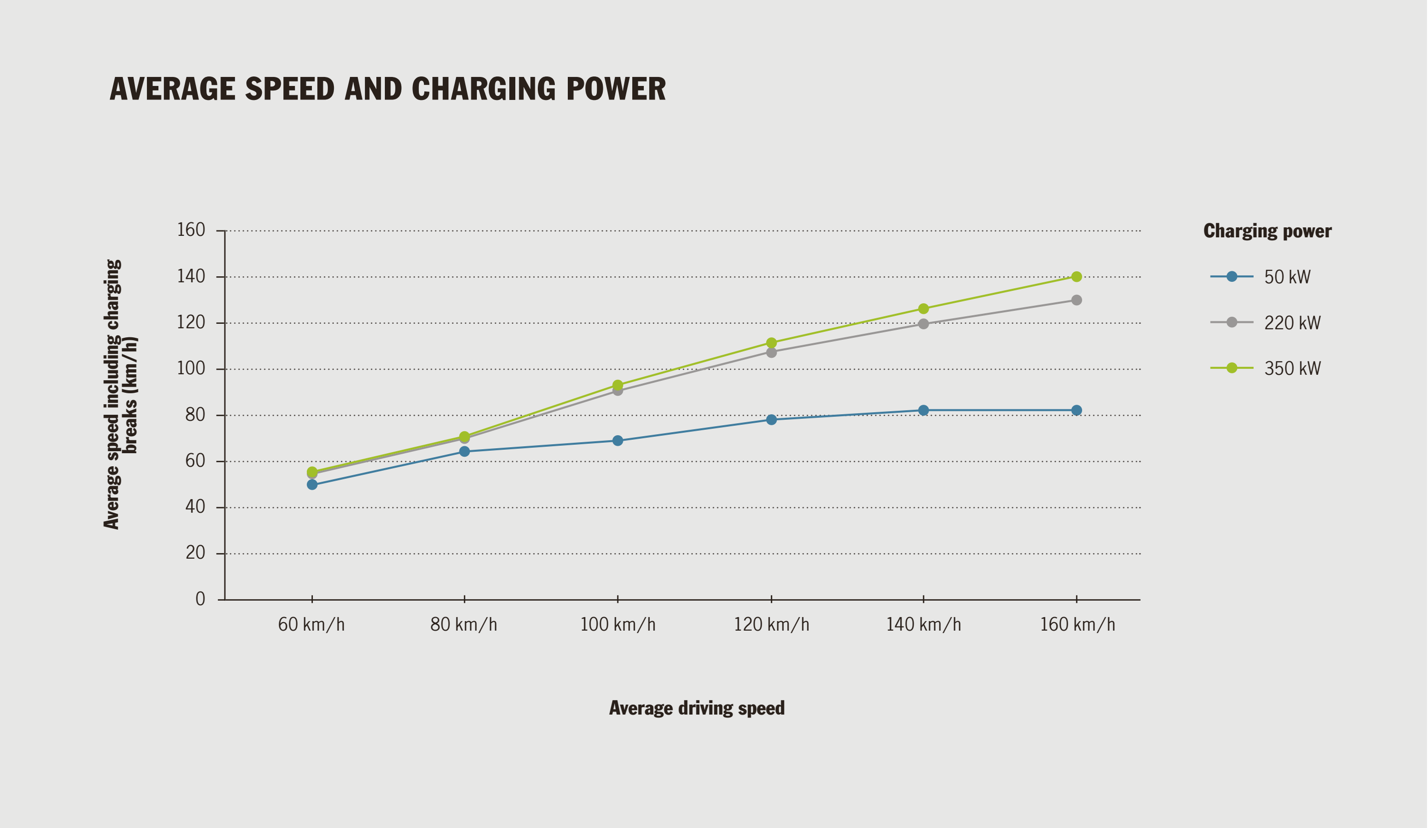


Figure 2

Get there faster with shorter charging times

The usefulness of a powerful charging infrastructure is illustrated by the example of the achievable average speed over a longer trip in relation to the charging power (figure 2).

A charging station with a 50-kilowatt charging power impacts the average speed over the entire route drastically due to long charging times. The use of a 220-kilowatt charging infrastructure would enable a noticeable improvement in the achievable average speed and accordingly shorter travel times. What that means in practice is demonstrated by the example of a long route: from Berlin to Lindau (see figure 3 on page 14).

For the route of approximately 720 kilometers, the example assumes one filling stop for a conventional vehicle with a combustion engine. At a good speed, the trip thus takes about 5.5 hours. If the same route is driven with an electric vehicle traveling at the same speed, two recharging breaks would be necessary. What that means is that with the currently ›

Prototype of an 800-volt DC charging station (cooperation between Porsche Design and the Charging Systems department at Porsche AG) available rapid-charging infrastructure, the same trip would require 45% more time. Using the rapid-charging technology with the target charging power of up to 350 kilowatts, the total travel time would be only about 10% longer.

In the future, the charging break for an electric vehicle will be no different, or only minimally so, than the average re-fueling stop today: The driver parks the vehicle at the charging station and starts the charging procedure. In the meantime, the driver can engage in normal break activities such as buying articles in the station, having a meal or using the restroom. Payment can be carried out while the charging is under way. Once all of this is finished, the drive can continue without delay in the recharged vehicle.

Economic benefits through disproportionately higher sales

For the operators of the charging infrastructure, both the investments and the economical operation of the charging station are relevant factors. A high-power charging infrastructure that can fulfill the described requirements requires extensive technological measures. The requisite investments for charging stations are therefore relatively high. Through a holistic view of the system from the grid connection to the charging socket, with a suitable design of the topology significant savings can be achieved for the cost-driving components. In a comparison of the specific costs (euro per kilowatt of charging power), a high-power charging infrastructure turns out to be significantly less expensive than the currently available 400-volt-based rapid-charging infrastructure. The reason for this is that the requisite base components are already in place and can thus be used more effectively.

The functional scope of the envisioned 800-volt high-power charging station enables charging of the currently available models as well as the next generation of electric vehicles with 400-volt technology. The interface to the vehicle is functionally and geometrically adapted to the CCS charging standard (Combined Charging System) and completely downward compatible.

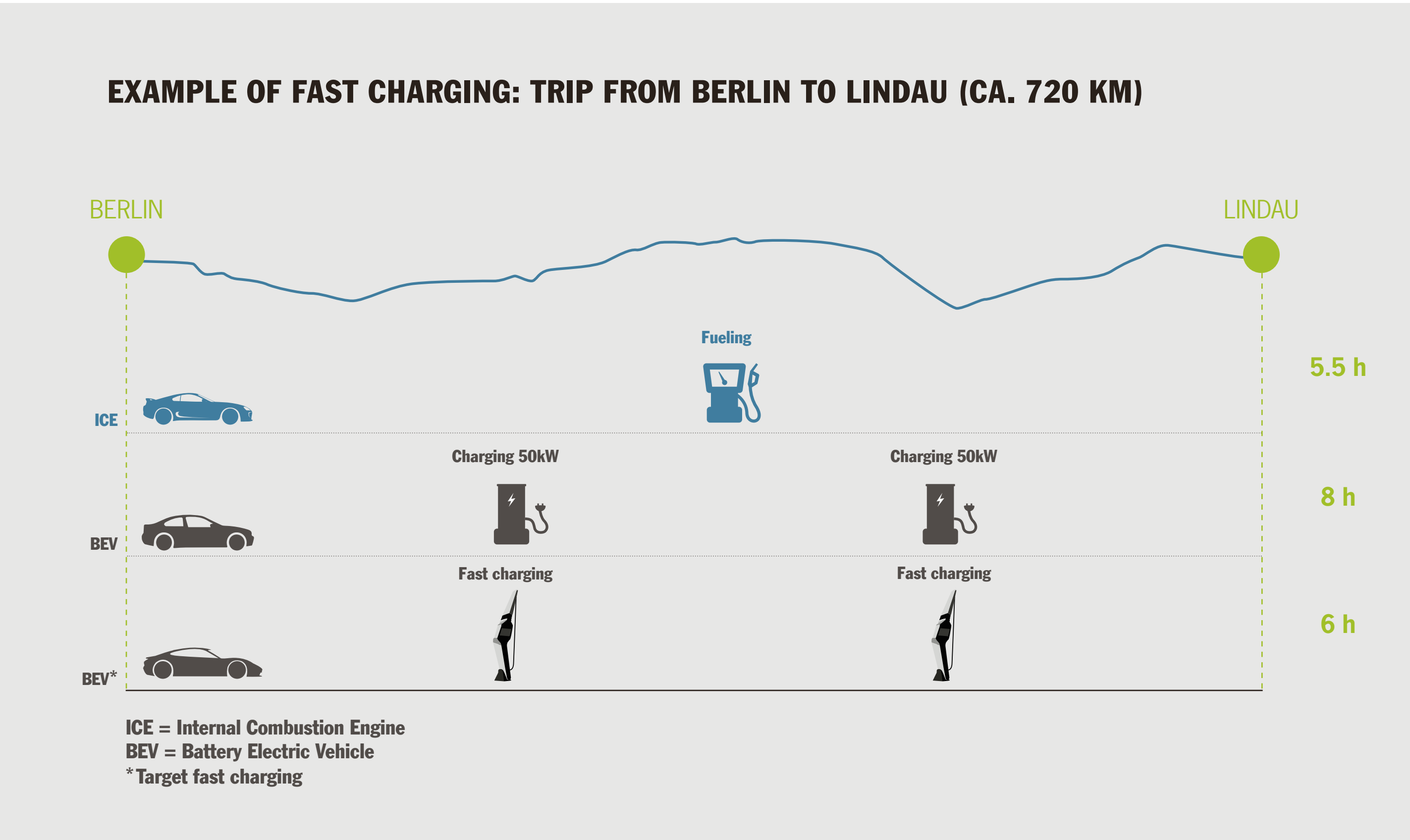


Figure 3

Mission E: tribute to tomorrow

Adaptation of the charging interfaces could also enable compatibility with other charging standards and vehicle categories. The power unit, comprised of the transformer, DC/DC converter and rectifier, remains unchanged. The charging voltage and charging power are configured in accordance with the requirements of the vehicle through the power unit. Only the interface to the vehicle has to be adapted, which would enable such options as inductive charging and charging via a pantograph for electric buses and commercial vehicles. And through substantial standardization of the components of the power unit, significant cost benefits could be achieved through scaling effects compared to the technology currently used on the market.

Improved prospects for electromobility

Raising the voltage to 800 volts in the infrastructure will enable significant reduction in charging times. Even working with the currently available cell chemistry, charging times are possible that would fit perfectly well with the travel profile of long-distance trips. The analysis of the technology required for that shows that this infrastructure can be implemented from a technical standpoint. And the economic efficiency is also compelling in terms of the customer benefit for both operators and users. ■

e-models

E-Machine Models—Approach, Usage and Validation

____ The increasing demands of the modern vehicle development process cannot be satisfied without employing sophisticated simulation tools. This is particularly true for electrified vehicles: the dynamic drive is able to provide short boosts of high power for a certain time, but quickly reaches its load limit. In order to be able to make precise predictions about output and consumption, for example, during every development phase, detailed simulations of the electrified powertrain are absolutely necessary.

By Dr. Malte Jaensch

Essential for accurate simulations of the performance of electrified vehicles are accurate electric machine models. The core of the E-drive seems to be very simply constructed at first glance: housing, rotor, stator and two bearings. On close inspection, however, it becomes apparent that it is indeed a very complex thermoelectromechanical device, the modeling and validation of which poses considerable challenges.

The complete vehicle model and its main components

An electric vehicle model suitable for the calculation of power and consumption comprises a large number of independent model blocks. The most important model blocks and how they interact are shown in Figure 1 in more detail.

The **driver model** takes on the role of a controller, comparing a vehicle speed set point, taken from a given **speed profile,** with the actual speed of the vehicle (as reported by the **vehicle dynamic model**) and using throttle and brake pedals to try and align both. A **control unit** translates the pedal position into a positive or negative torque demand, which is sent to the inverter. The **inverter model** then applies a matching AC current to the **electric machine model,** which sends back to the inverter information on the level of AC voltage occurring at the machine's power terminals. The **battery model** governs—inter alia—the relationship between DC current and DC voltage, where—as with the E-machine model, the current is taken to be the input and the voltage is the output of the model.

Within the electric machine, a power conversion from electrical to mechanical power is taking place. In motoring mode, the **electric machine model** accepts current and outputs torque, which is then used as an input to the drivetrain model. The **drivetrain model** block represents driveline components such as gearbox, differential and clutch. Having thus been manipulated by the drivetrain model, torque enters the **vehicle dynamics model** that computes the reaction of the vehicle in terms of vehicle and tire speed, weight balance, tire slip and so forth.

Many of the components that constitute the electrified powertrain require liquid cooling in the real vehicle. The corresponding component models therefore have thermal sub-models that use the coolant temperature as their input parameter. The change in temperature is calculated based on this and depending on the model block-specific losses in each case.

Electric machine modeling

A typical electric machine model is made up of four building blocks: the electromagnetic model, the power loss model, the thermal model and the mechanical model (see figure 2 on page 18).

The **electromagnetic model** serves two main functions: first, it calculates the AC voltage as a function of AC current, torque angle, angular frequency, winding (copper) temperature and magnet temperature. Second, it computes the internal torque as a function of current, torque angle, power loss and magnet temperature.

The **power loss model** computes the losses occurring inside the electric machine based on parameters such as current, torque angle, angular frequency and temperature. In order to cover a variety of different loss types, the power loss model is also made up of individual sub-models.

The **thermal model** calculates the temperature of the model components such as winding, stator, rotor and housing, as well as the initial coolant temperature. The flow rate and input temperature of the cooling medium are taken into account.

The **mechanical model** can be very basic, only considering the role of the E-machine's inertia in computing the output torque available.

Considering this simplified description of the inner workings of the electric machine model, it becomes apparent that there is a high level of interdependency between the individual modeling blocks, which is further increased by the regulating actions of the inverter. Modeling this complex behavior accurately is one of the greatest challenges for the simulation.

The quality of a simulation is determined by how close to reality its results are. Before the model of the electric machine can be used as part of a complete vehicle model, the model created needs to be checked for accuracy. This is done by comparing computed results with data gathered from the electric machine test stand.

Electric machine measurement for model validation

The simplified example of a test plan, as might be used by an OEM as part of the series development of the electric machine, consists of six major types of testing (see figure 3 on page 19).

Starting with tests to determine the fundamental machine parameters, a range of test programs are executed: mechanical testing, which subjects the machine to mechanical loads on housing and shaft; environmental testing that exposes the machine to adverse environmental conditions such as salt, water and heat; three sets of endurance testing, performed under varying climatic conditions and, most important from the viewpoint of the simulation engineer, performance testing. ›

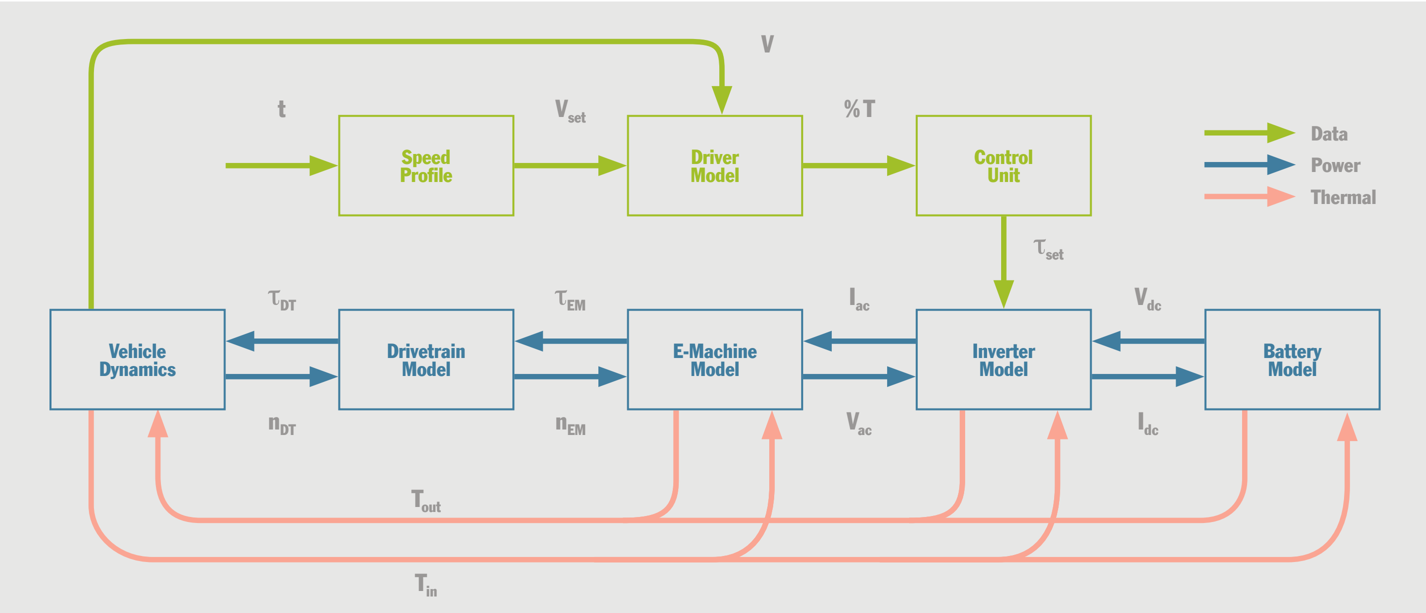


Figure 1: Outline of a simplified simulation model of a battery-electric vehicle

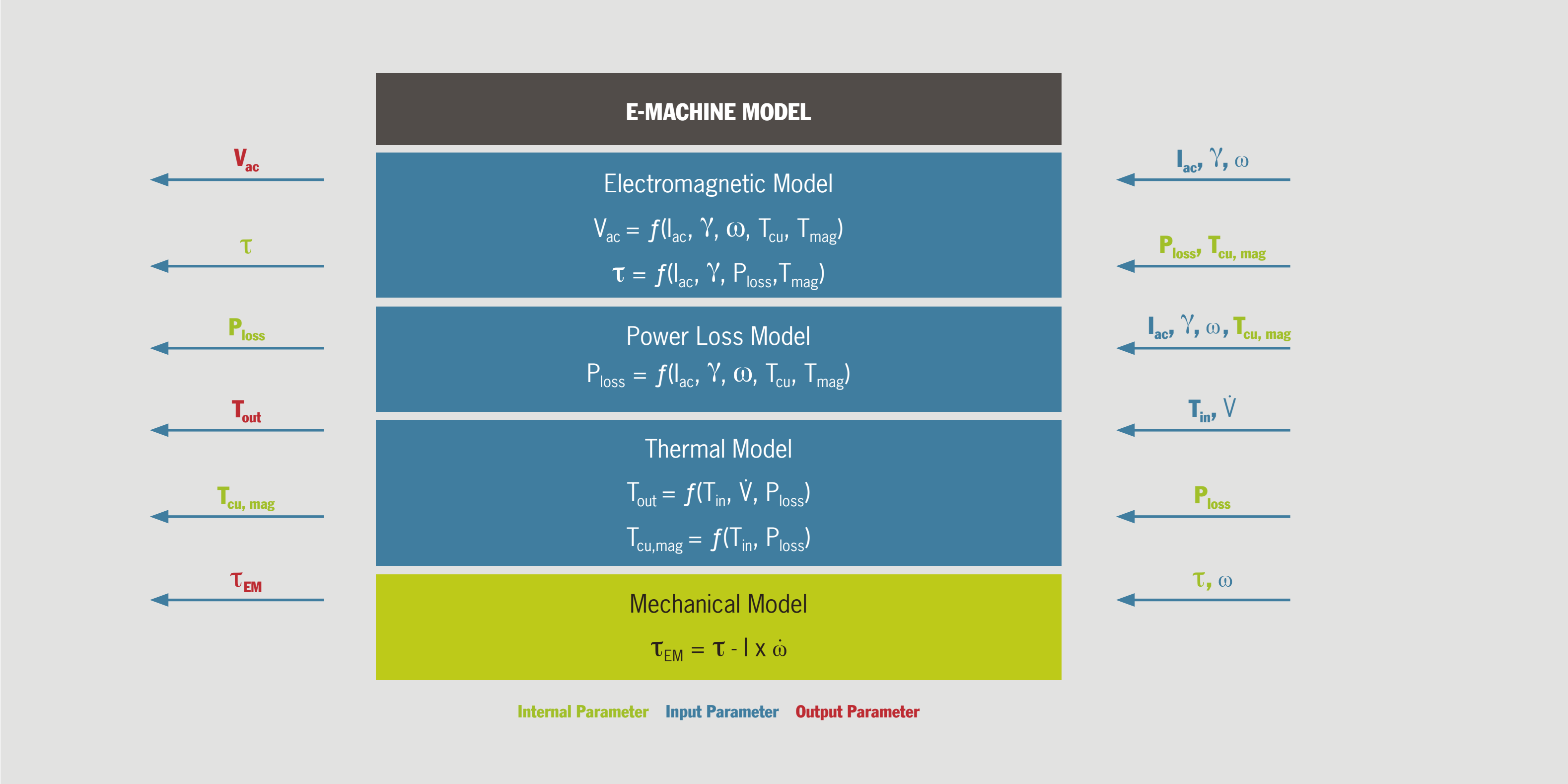


Figure 2: Building blocks of an electric machine model

For the validation of the E-machine models, the results of the performance testing and the inspection of the machine parameters are extremely important, even if they alone are often not sufficient for a complete validation. The measured data do, however, provide the basis for model validation. If the comparison of the measured and calculated results shows too great a deviation, the geometry, material properties and/or model coefficients are adjusted. What the model tells us is thus moved closer and closer to the real measured data successively by means of repeating the steps (simulation—measurement—comparison—change).

Validating the electromagnetic model

In order to validate a complex sub-model, additional special tests are often required, as shown by the following five examples:

Comparison of calculated and measured open circuit voltage

A very simple and useful test for validation of the electromagnetic model is the comparison of the calculated and measured open circuit voltage. The open circuit voltage can be measured during passive rotation of a (synchronous) machine at the electrical connections (see figure 4 on page 20). Basic modeling errors, such as wrong geometry or faulty winding patterns, become obvious immediately.

Apart from the engineers' skills and knowledge, the accuracy of the models is determined by the modeling approach chosen: the finite element method (FEM) provides extremely accurate results, while analytical approaches, such as the waveform of the AC voltage, can only provide an approximate picture.

Comparison of torque and current

An additional test used for the validation of the electromagnetic model is based on the interdependency of torque and current (see figure 5 on page 20). At low speed, the AC current is increased incrementally and the resulting torque is measured in each case. At high currents, saturation effects in the iron lead to a diminishing marginal utility of the current. As to whether—and how—this effect has been or should be taken into account during model formation, can only be determined by means of a comparison of calculation and measurement.

FUNDAMENTAL PARAMETER TESTING (START OF TEST PROGRAM)					
Mechanical Testing	Environmental Testing	High Temperature Endurance	Heat Cycle Endurance	Humid Heat Endurance	Performance Testing
Axial Loads	Temperature Shock	High Temperature Endurance	Heat Cycle Endurance	Humid Heat Cycle Endurance	Passive Testing
Radial Loads	Salt Spray				Power Curves
Torsional Loads	IP Testing	Mech Shock & Vibration	Mech Shock & Vibration	Mech Shock & Vibration	Efficiency Mapping
FUNDAMENTAL PARAMETER TESTING (END OF TEST PROGRAM)					

Figure 3: Overview of standard electric machine test schedule

Measuring drag losses

The power loss model comprises several different individual loss models that, taken together, determine the behavior of the E-machine. Power losses are the fundamental link between the electromagnetic and the thermal model and the subject of many optimization approaches.

Drag losses comprise mechanical and electromagnetic iron losses caused by the rotor's rotating magnetic field interacting with the stator (see figure 6 on page 20). These losses can be separated into mechanical and electromagnetic iron losses by repeating the test with a machine where magnets have been removed or replaced with passive material. This enables them to be measured by passively spinning the machine across a range of speeds and recording the torque required.

Calculation of copper and iron losses

In addition to the mechanical and iron losses, ohmic losses in the copper winding also play an important role. The calculation of these copper losses is quite simple in most cases, as long as resistance and temperature are known. Furthermore, this also allows iron losses to be derived from a measured overall loss during a test (see figure 7 on page 21). Iron losses themselves can be further subdivided into eddy current and hysteresis losses, identifiable by their respective frequency dependency and thus be used as the basis for validating the sub-models in question.

Validating the thermal model

The last example shows how a simple test can be used to adjust the capacities and resistances of the thermal model: at a set speed, the machine is subjected to maximum torque. Consequently, temperatures rise until a certain threshold is reached, where power is reduced by the inverter to prevent the machine from overheating (this is known as "Derating"). The machine reaches its stabilized state after approximately 30 minutes (see figure 8 on page 21).

In the first few seconds of the peak power phase (S6) losses accumulate predominantly in the thermal masses of the E-machine during the first few seconds. Measured temperature gradients can therefore be used to validate the respective heat capacities. Once the machine has stabilized and delivers nominal power (S1), there is no net ›

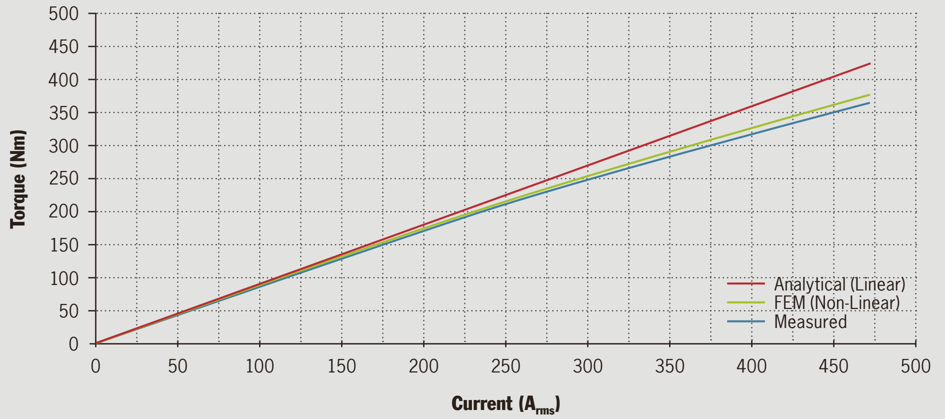
Input:
Speed

Output:
Voltage

Properties/models to be validated:
> Geometry of stator and rotor
> Winding diagram
> Material properties

Test procedure:
> Spin passively at set speed
> Measure voltage wave
> Comparison with calculation

Figure 4: Comparison of calculated and measured open circuit voltage



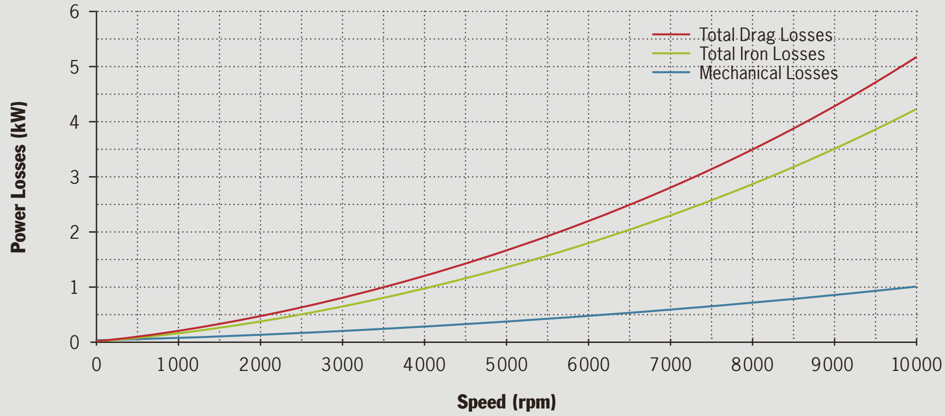
Input:
Current

Output:
Torque

Properties/models to be validated:
> Torque generation
> Flux distribution
> Material properties

Test procedure:
> Drive machine against load
> At constant speed increase current
> Measure torque
> Compare with calculations

Figure 5: Interdependency of torque and current



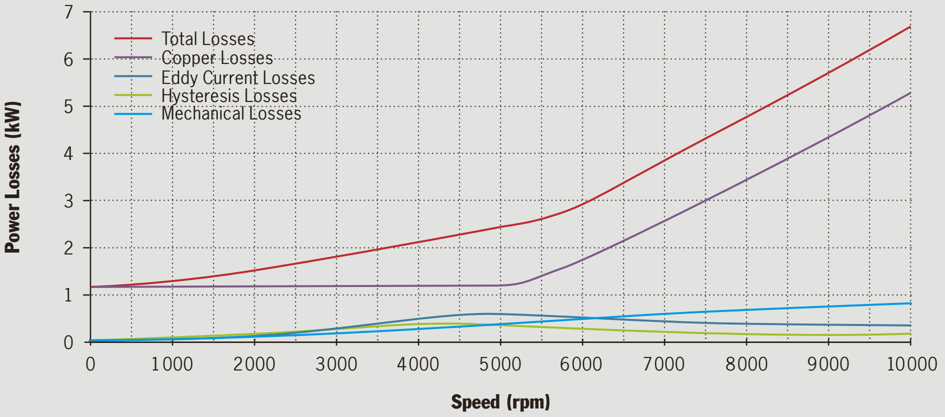
Input:
Speed

Output:
Power loss

Properties/models to be validated:
> Mechanical loss model
> Iron loss model

Test procedure:
> Drag machine at varying speed
> Measure power required
> Compare with calculations
> Test with & without magnets

Figure 6: Drag losses across the rotary speed range



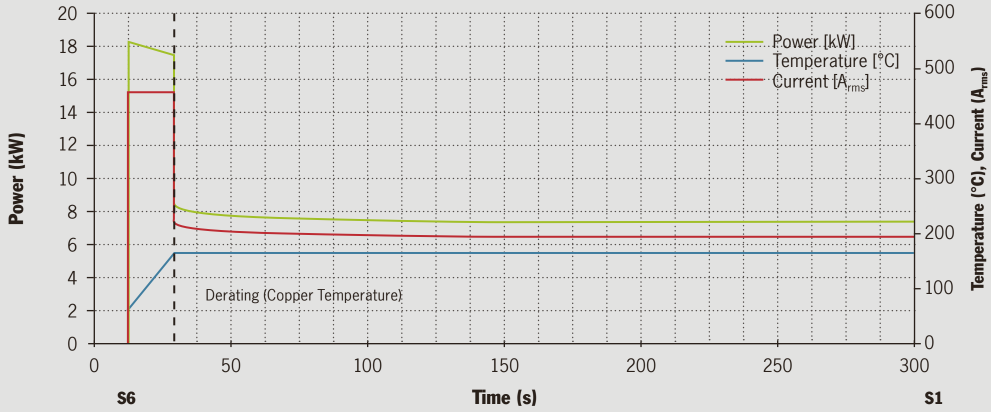
Input:
Current

Output:
Power loss

Properties/models to be validated:
> Individual components of power loss

Test procedure:
> Measure power loss
> Calculate copper and mechanical losses
> Split iron loss by frequency
> Compare with calculations

Figure 7: Power loss at constant torque



Input:
Current

Output:
Temperatures

Properties/models to be validated:
> Thermal capacities
> Thermal resistance

Test procedure:
> Measure maximum torque
> Derating at max. temp.
> Measure stabilized state
> Compare with calculations

Figure 8: Development of power, current and temperature

power flowing in or out of the thermal masses. Thermal capacities and thermal resistances can therefore be measured separately. The values thus determined can now be used as coefficients for the thermal model.

Summary

E-machines are highly complex electrothermomechanical systems. Every model must take this into account if it wants to enable exact simulation results.

The validation of the E-machine model and its diverse submodels, which is absolutely necessary for a precise and viable calculation, requires comprehensive testing on the test stand. The basic data set is supplied by the OEM tests that are carried out as part of standard testing. The validation of complex models, however, requires additional measurements.

The integration of modeling and measuring of the E-machine is essential for a precise simulation of the behavior of an electrified powertrain. As it is at the heart of the electrical powertrain, the E-machine affects the behavior of the entire vehicle. ■

e-functionality

System Functionality Thanks to Electromagnetic Compatibility

____ Today, a never-ending stream of new radiocommunication services controls systems wirelessly, accesses information and enables increasingly diverse communication options. In electric vehicles, all of this technology is paired with increasingly powerful electrical energy flows to and within the vehicle. To ensure that this confluence of factors happens without disturbances, securing electromagnetic compatibility (EMC) in the context of electromobility is more important than ever.

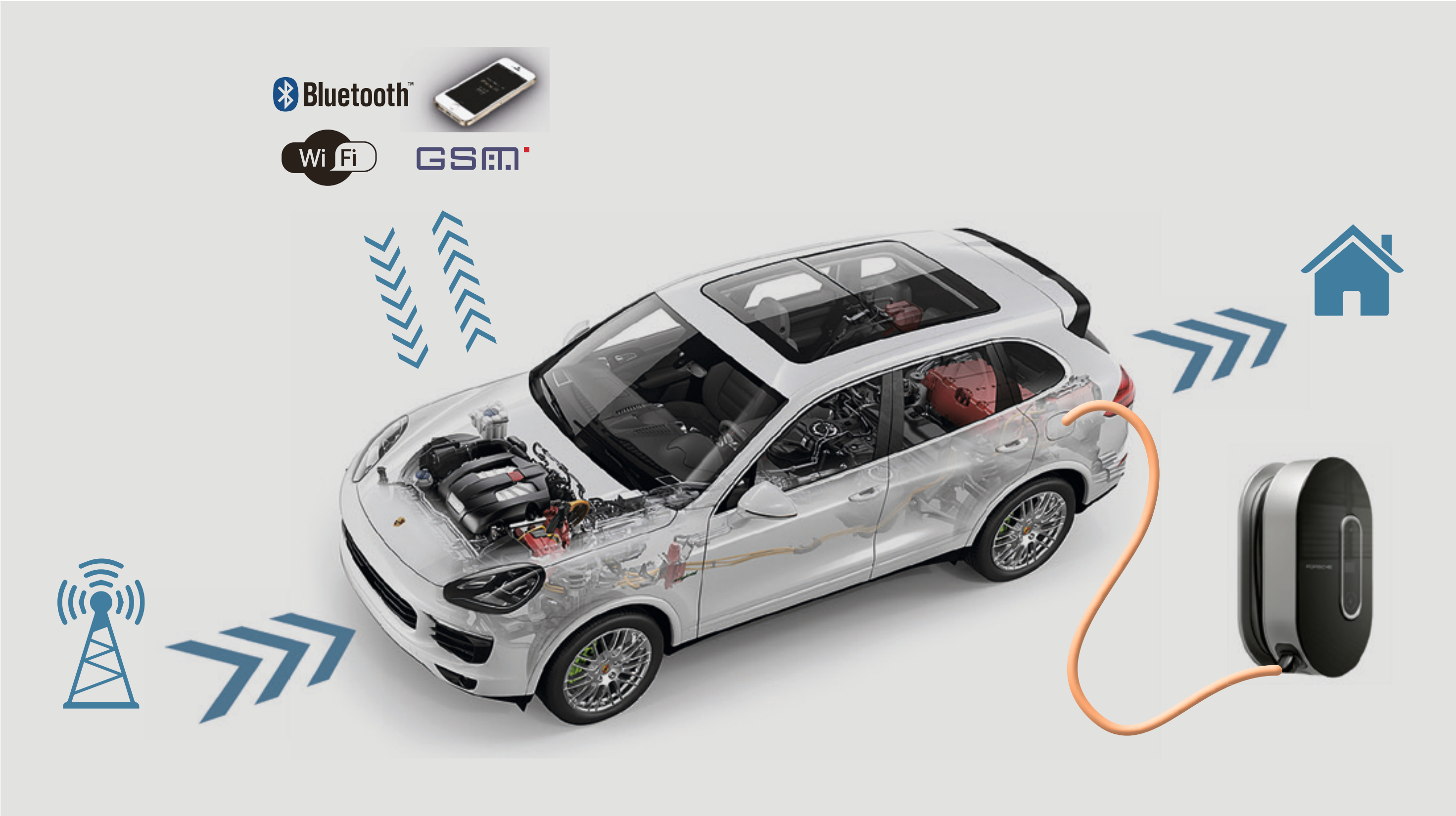
By Jan Spindler
Photos by Steffen Jahn

CAYENNE S E-HYBRID
Fuel consumption (combined): 3.4 l/100 km
Electricity consumption (combined): 20.8 kWh/100 km
CO_2 emissions (combined): 79 g/km
Efficiency class: A+

The topics of EMC and electromobility are not new. As far back as 1892, the "Law on Telegraphy of the German Empire" was passed by the German parliament and is regarded worldwide as the first law that concerned itself with the effects of electromagnetic interference on devices and installations of the telegraph network. At roughly the same time, Ferdinand Porsche was working on a wheel hub motor as part of a development project for the Hofwagenfabrik Jacob Lohner & Co. of Vienna. This development, in turn, led to the "Lohner-Porsche wheel hub car" in 1900.

Challenges of the future

While electric vehicles played a marginal role until just a few years ago, the importance of EMC rose continuously over the years due to increasingly complex communication systems. In addition to the analog radio broadcasters, digital information services such as DAB and DVB-T, mobile radiocommunication services such as GSM and LTE, WiFi and Bluetooth became a part of everyday life, and thus also of cars. Ever higher clock rates, performance and package densities heighten the EMC demands as well. Low- and high-voltage systems, communication and power supply cables, antennas and potential sources of interference are packed into tight quarters. Moreover, new voltage levels are being introduced in vehicles, with 48-volt, 400-volt and 800-volt systems (see also "e-power" on page 10 as well as issue 2/2015 "Dynamic Vehicle Electrical System Simulation"). These developments require clear regulations in terms of electromagnetic compatibility in order to ensure the proper functioning of components both within and outside of the vehicle. Without clear regulations, neither the safety nor the technical functionality of the vehicle systems can be assured. ›



A hybrid vehicle in its electromagnetic environment

Meaning of electromagnetic compatibility

Electromagnetic compatibility is currently defined by the European Directive 2014/30/EU as

"the ability of equipment to function satisfactorily in its electromagnetic environment without introducing intolerable electromagnetic disturbances to other equipment in that environment."

In order to ensure the proper functioning of the components and services, it is essential to define requirements and take account of EMC in the development process. A critical distinction in this regard is made between interference immunity and emitted interference requirements. The assessment of **interference immunity** deals with the protection of the driver, passengers and other traffic participants. Emitted and conducted interference can cause functional impacts associated with distraction of the driver and other traffic participants, and affect the vehicle data bus. Scenarios such as the malfunctioning of headlights and tail lights, or even the failure of control units, are absolutely plausible.

With **emitted interference,** the focus is on protecting electric and electronic systems in the vehicle as well as in other vehicles and systems in the vicinity. It is important in this regard to protect radiocommunication services in the AM and FM ranges, for example, which are used by authorities and other civilian services.

Similar requirements apply to charging systems, as they are located in residential and commercial areas. It is key to ensure that even when charging a vehicle, unimpeded radio reception is assured. At the same time, the charging station itself must be resistant to interference to ensure that the charging process proceeds reliably.

Definitive approval procedure according to ECE R 10

The definitive standard for the approval of vehicles with regard to electromagnetic compatibility is ECE R 10. In its current version, revision 5, requirements for vehicles with RESS (Rechargeable Energy Storage Systems) were added, making it applicable for plug-in hybrids and electric vehicles. One substantial extension of the regulations pertained to specifications for the interface to the charging station and thus to the public power grid. The move reflected the fact that PHEV (Plug-in-Hybrid-Electric Vehicles) and BEV (Battery-Electric Vehicles) represented the first direct contact between the world of private automobiles and the low-voltage grid. There are also requirements, however, that are new to the automotive industry. The conducted interference measurement procedures with regard to interference emission measurement of harmonics and flickers were previously not taken into account in automotive development.

Current series vehicles work with charging powers of 3.6 to 22 kilowatts, which are covered by AC charging systems. The vehicle is connected via one-phase (230 volts) or three-phase (400 volts, 16 amperes or 32 amperes) connections. In the EMC chamber, these connections are typically filtered, enabling the vehicle to be connected directly via the artificial network.

The increasing expectations in terms of range and duration of the charging procedure require higher charging power. Charging systems with capacities of over 100 kilowatts utilize DC charging. To conduct the required EMC measurements during charging, these charging systems must also be set up in the EMC lab. To ensure that no interference is directed into the EMC hall, the DC lines must be filtered. This requires an interface outside of the EMC hall that enables the connection of charging systems of over 100 kilowatts.

Beyond the necessary space and the connection capacity, these systems also give rise to requirements in terms of the set-up. In addition to the DC cables, communication cables are necessary to enable the vehicle to communicate with the ›

The interface between the vehicle and the charging infrastructure requires new measuring procedures in the areas of testing and EMC. These procedures need to be established and safeguarded in order to guarantee the functionality and robustness of the system.

DC charging station and the operator control unit. These are usually led into the EMC hall in the form of fiber optic cables and are connected to specially developed PLC modems (power line communication). As a modem is located inside the hall during the EMC test, it must be resistant (immune) to the electromagnetic fields and pulses emitted into the hall and must not, if possible, emit any electromagnetic fields itself (low-emission). To eliminate influences from the periphery to the greatest possible degree during the classification of BEV and PHEV vehicles, an extensive measurement set-up is therefore necessary.

Need for development in high-voltage systems

The power electronics in electric vehicles are developed with the aim of achieving higher degrees of efficiency. The fast switch events required for this lead to high interference spectrums in the high-voltage vehicle electrical system. Current vehicles with high-voltage systems have shielded cables that have a shielding effect with regard to EMC. In the current concepts, however, the charging plug for DC charging is a weak point as the shielding concept cannot be comprehensively implemented in this case. The reason: The charging plug is not a coaxial connector. The shield can therefore not be connected with a low HF contact resistance, as is required for the plug connections of high-voltage components. The DC cables from the charging station are also not shielded, which means that interference from the high-voltage vehicle electrical system can also be emitted. It can therefore be expected that limits will be exceeded in conducted disturbances on DC power lines unless alternative measures are devised.

In addition, the OEMs also demand that it be possible to receive radio / TV / DAB during charging even with shortened charging times of around 15 minutes. These demands are not taken into account in ECE R 10 as receiver systems within the vehicle are significantly more sensitive. With regard to emitted interference, the international standard CISPR 25 should also be taken into account, which defines thresholds and protective measures for receivers in vehicles and boats as well as devices powered by combustion engines.

If one compares the threshold values for conducted interference emissions in both systems, it turns out that in the medium-wave frequency range, the threshold value (26 decibels) for the average detector under CISPR 25 is below the requirements of ECE R 10. To fulfill the requirements, suitable DC filters must be installed between the high-voltage battery and the charging connector. Depending on the application, voltage ranges of up to 800 volts and currents of 200 amperes are possible.

It remains essential to position high-voltage and DC cables in the vehicle as separately as possible to reduce cross-coupling. Particularly within the high-voltage battery, there is a confluence of high-voltage cables and communication cables that are necessary for monitoring the cells and which communicate with the battery management system (BMS). If this communication is disturbed by interference from the high-voltage cables, this can lead to the failure of communication blocks or even the termination of communication entirely. The BMS will react in this case and open the high-voltage contacts for safety reasons. OEMs therefore place a great deal of importance on robust communication procedures and interference-immune cell controllers that are resistant to disturbances from the power supply lines of the cell controller.

Inductive charging systems as a challenge for the future

Electromobility and EMC will be inextricably linked in the future as well. Additional new challenges will be posed by inductive charging systems, for example, which will be dealt with in the coming revisions of ECE R 10. Together with new technologies in the field of electromobility, the number of PHEV and BEV vehicles will continue to rise. As a logical consequence, the infrastructure of rapid charging stations with capacities significantly over 100 kilowatts will continue to grow as well. ■

e-opportunity

Chances and Challenges through Digitization and Electrification

Uwe Michael

Uwe Michael (56) studied electrical engineering at the Darmstadt University of Technology, with a focus on solid-state electronics. After receiving his Dipl.-Ing. degree, he held a number of positions over 15 years at the automotive supply company VDO Automotive AG. He then headed a division at Mannesmann AG in charge of the sites in Wetzlar (DE), Eindhoven (NL), Rambouillet (FR), and Sophia Antipolis (FR). Uwe Michael joined Porsche in 2001 and has directed electrical and electronic development ever since.

____ An interview with Uwe Michael, Head of Electrical and Electronics Development at Dr. Ing. h.c. F. Porsche AG.

In terms of technologies and positioning, how is the traditional automotive industry responding to current and future megatrends such as digitization?

Uwe Michael The automotive industry will intelligently tie together these megatrends and enable customers to experience them at the highest levels of safety and quality—that capacity has distinguished us throughout our history. As part of the migration of assistance systems to a higher degree of automation, elements such as sensor, object and map data will be fused together to enable convenient and energy-efficient driving and parking. After the implementation of personalized and vehicle-specific Car Connect services, the front is now shifting towards the use of comprised vehicle and personal data, in the form of swarm and cloud intelligence. This enables predictive functions that quickly come to seem indispensable to anyone who has tried them.

"The electric motor enables completely new concepts and opportunities not merely to satisfy customers, but to enthuse them."

What role do battery and charging technologies play with respect to customer acceptance of new electrically powered vehicles?

Uwe Michael The range and charging times of electric vehicles are two important factors in the effort to generate customer enthusiasm for electric vehicles. Alongside battery manufacturers, the aim is to create electric vehicles that are not simply equivalent to combustion engine vehicles, but actually superior to them.

The prospect of greater electric ranges is there, but costs and weight must still come down substantially. On the other hand, there seems to be a breakthrough in the offing with regard to the much-criticized long charging times through the switch to rapid charging with 800 volts instead of 400. There is a real need for greater engagement on the part of the government and the national electromobility platform in terms of infrastructure expansion.

What changes need to be enacted in terms of the processes and structures of automobile manufacturers in the context of the digital transformation? And what role is played in that by specialized development centers such as Porsche Engineering's software development office in Cluj-Napoca, Romania?

Uwe Michael We need to modernize our ways of thinking and processes if we want to continue to set the tone. Success factors such as cross-industry partner models, short development cycles and tying together product and lifestyle worlds are guiding principles for our strategies. Having a location like our office in Cluj-Napoca, our new software location in Romania, will be helpful in that. There we can develop concepts and ideas in parallel with our core development processes in a dynamic environment and implement those ideas in later series projects. This is one of many building blocks that we're working with in order to continue to delight our customers and stay ahead of the competition in the future.

Porsche will bring its fully electric Mission E to the market by the end of the decade. How is Porsche confronting the challenges in terms of development and customer acceptance that arise with such a new type of vehicle?

Uwe Michael The Mission E is a new car, but we're not exactly starting from scratch with the topic of electromobility. Porsche invented the hybrid drive system and we were the first manufacturer to introduce hybrid drives in three different vehicle classes. And in 2015 we won the FIA WEC championship with the hybrid-powered Porsche 919. Just as in motor racing, with the Mission E we aim to exceed expectations and demonstrate how we envision the future of electric sports cars.

Thanks to the 800-volt charging technology in the Mission E, it is possible to achieve an 80% charge in less than 15 minutes. Fully charged, we can achieve ranges of 500 km. With 600 hp, the car accelerates from 0 to 100 km/h in less than 3.5 seconds. And it has a top speed of 250 km/h. The electric motor enables completely new concepts and opportunities not merely to satisfy customers, but to enthuse them. But the Mission E will not only usher in a new era in terms of electromobility; it will also set new standards for the coming decade with respect to the interior, the control concept, connected functions and the design language. ■

100% Testing

Testing Services from Porsche Engineering

____ Every single development, from the smallest component to the overall vehicle, needs to be tested until it is ready for series production. The testing services offered by Porsche Engineering combine unique resources like the Nardò Technical Center in southern Italy with expertise and experience from sports car series development. All over the world the testing contains varied course profiles as well as comprehensive trials and includes all the requisite evaluations. Join us as we test the new Porsche 718 Boxster.

By Nadine Guhl
Photos by Steffen Jahn

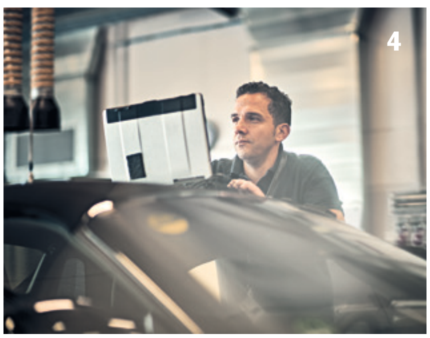
718 BOXSTER
Fuel consumption (combined): 7.4–6.9 l/100 km
CO_2 emissions (combined): 168–158 g/km

1 Start Giancarlo Vella, who is in charge of the upcoming test of the new 718 Boxster, picks up the car from the customer to drive it to Nardò. The task: to perform long-distance, customer-specific endurance testing including predetermined trials on defined course profiles in a very short period of time. After checking the vehicle and handling all the formalities, it's time to set off.

2 Ride As a long-distance drive, the 1,600-kilometer ride from Weissach to Nardò represents the first major stage of the customer-specific endurance trials. It marks the start of simulating the vehicle aging process in order to test it under different conditions.

3 Arrival and check-in at Nardò Technical Center Security regulations and confidentiality agreements require driver and vehicle registrations for the proving ground to be done in advance. The relevant test courses are also reserved beforehand.

4 Preparation A preliminary check is done at the workshop and the car is prepared for the next stage. High-speed tests are run on the 12.6-kilometer circuit. In the course of what is called a “federal freeway replacement program,” the car is driven at its maximum speed—in this case 275 km/h. This job is done by a professional test driver. Racing gear and helmet are mandatory. ›



5 Communication Drivers can contact the test supervisors or safety personnel at any time via radio, for example to pass on information or warnings.
6 Car circular track entry A transponder has been installed in the vehicle to identify it for entry onto the circular track. The barrier rises. The car now faces a drive at very high speeds with all the corresponding intensity and strain.
7 Car circular track The degree of banking on the circular track enables the car to be driven at 240 km/h on the outermost lane without needing to steer inwards. Supreme concentration on the part of the driver is always demanded. Physicians check the drivers' health and fitness at regular intervals.
8 High-speed drive conclusion When this test stage is over, the results are saved and a first summary is drafted. The driver reports all details to the test manager and hands over the car.


5

7


6


8

9 Additional tests Various operational and driving processes are carried out as part of the endurance test, for example on the Rolling Tracks and Dynamic Platform.

10 Planning the next day While with the upcoming night shift the next stage of testing starts, Giancarlo Vella is planning the details for the next day. “Precise preparation and planning are essential in order to complete the full scope of the customer’s test program within the allotted time frame,” he says. ›

11

12

13

11 The next day After the night shift further testing starts at an early hour of the morning. Today’s program consists of country roads and city drives. After checking out at the gate, the Porsche 718 heads out onto the roads of Apulia …

12 Country roads As the sun rises, the test car sets off toward the north. “Of course we are also interested in poor road surfaces,” says Vella. “We run a number of tests to examine precisely how the car operates in that type of extreme situation.”

13 Mountain roads in southern Italy Challenging mountain roads in Apulia demand a good deal from the clutch, brakes, chassis and tires. A flock of sheep crosses the road, requiring deceleration in what is otherwise a very concentrated and strenuous drive.

14

14 Break The refueling stop is also used to open and close the top, windows and luggage compartment, and to document the results of the drive thus far—always in accordance with the customer's requirements and specifications.

15 On tour The speed is reduced while driving through villages, but the largely straight sections of highway segments on the specified routes offer good opportunities to test the car's driver assistance systems.

16 The day is nearly over After completing the test unit, the car heads back to the Nardò Technical Center. When the new shift takes over, the drivers and test directors get together to discuss the results. Additional drives—on both proving grounds and public roads—still need to be run before the test program is completed as specified by the customer. When all the tests have finally been performed and evaluated, the results are handed over to the customer in Germany together with the car. ■

15

16

718 BOXSTER/718 BOXSTER S
Fuel consumption (combined): 8.1–6.9 l/100 km
CO_2 emissions (combined): 184–158 g/km

Two Generations, One Idea

Porsche 718 Boxster

____ A legend renewed: With the 718, Porsche is relaunching its mid-engine roadster. In the late 1950s, the Porsche 718 was one of the most successful race cars and sports cars on the scene. The new two-seater is now renewing the link to the concept of its renowned mid-engine predecessor. A powerful four-cylinder flat engine—today with turbocharging—, resolute lightweight design, and exceptional driving dynamics distinguish the Porsche 718 today just as they did in the past.

By Peter Weidenhammer

When Porsche launched the Boxster 20 years ago, the roadster was presented as the legitimate successor to the 550 from the 1950s. That legendary sports car in which Hans Herrmann drove under a closed railway crossing gate in the 1954 Mille Miglia, and which became immortal with James Dean. Just as the Porsche 718 was once the successor to the 550, today the 718 Boxster is taking the place of its predecessor. And it's not the only parallel in this generational transition: With the type designation, the new roadster comes even closer to the original from 1957, particularly in terms of fundamental vehicle characteristics. ›

Jean Behra crossing the finish line in the Porsche 718 RSK Spyder at Le Mans, 1958

The engine: high-performance four-cylinder flat engine

The most prominent connection between the original 718 and its modern successor models is the flat-four engine. The engine of the original remains one of the jewels of engine design to this day. Based on the engine in the original Volkswagen, Porsche had developed a high-performance engine for racing purposes. The gas charge cycle in particular had been modified: The intake and outlet valves of the two-valve design controlled individual overhead camshafts. The four camshafts were powered by vertical shafts: Each led from the engine housing to the outlet camshaft, which in turn was linked to the inlet camshaft with another vertical shaft. The engine therefore boasted optimal engine speed stability for sporty driving, ranging up to 8,000 rpm. Two downdraft carburetors ensured adequate mixture formation. Two completely independent ignition systems enabled dual ignition with adjustable ignition delay. In the 718 RSK of 1957, the engine parlayed 1.5 liters of displacement into 109 kW (148 hp) at 8,000 rpm. Some 72 kW (99 hp) of power output per liter is nothing to sneeze at even 60 years later.

The technology today is different, but the philosophy is the same: high and efficient performance combined with robust reliability. Not to mention the typical advantages of flat engines, such as excellent mass balancing, high revving ability, a low center of gravity and the typical sound.

With the 718 Boxster, Porsche is introducing two completely new flat-four engines with turbocharging: a two-liter engine with 220 kW (300 hp) in the Boxster and a 2.5-liter engine with 257 kW (350 hp) in the Boxster S. Compared to the respective predecessor models, that amounts to a power increase of 26 kW (35 hp) in each case. And the torque has risen significantly as well. The two-liter engine in the 718 Boxster generates 380 Nm of torque between 1,950 rpm and 4,500 rpm. That represents an increase of 100 Nm, or 35%. For its part, the 2.5-liter engine in the 718 Boxster S generates 420 Nm of torque between 1,900 rpm and 4,500 rpm, or 60 Nm more than its predecessor model. That's the biggest torque increase with the introduction of a new engine in the history of the Porsche Boxster.

Better driving performance, low consumption

The new 718 Boxster models handle short bursts of speed much more dynamically and accelerate even faster from low engine speeds than they did before. The 718 Boxster with PDK and Sport Chrono package goes from 0–100 km/h in 4.7 seconds, while the 718 Boxster S with the same equipment manages the standard sprint in just 4.2 seconds. And the engine likes to rev, like any sports car: The rpm range extends to 7,500 rpm, while the power loss between the rated speed and the maximum engine speed is just 5%. No other turbo engine in the Boxster's segment achieves this value.

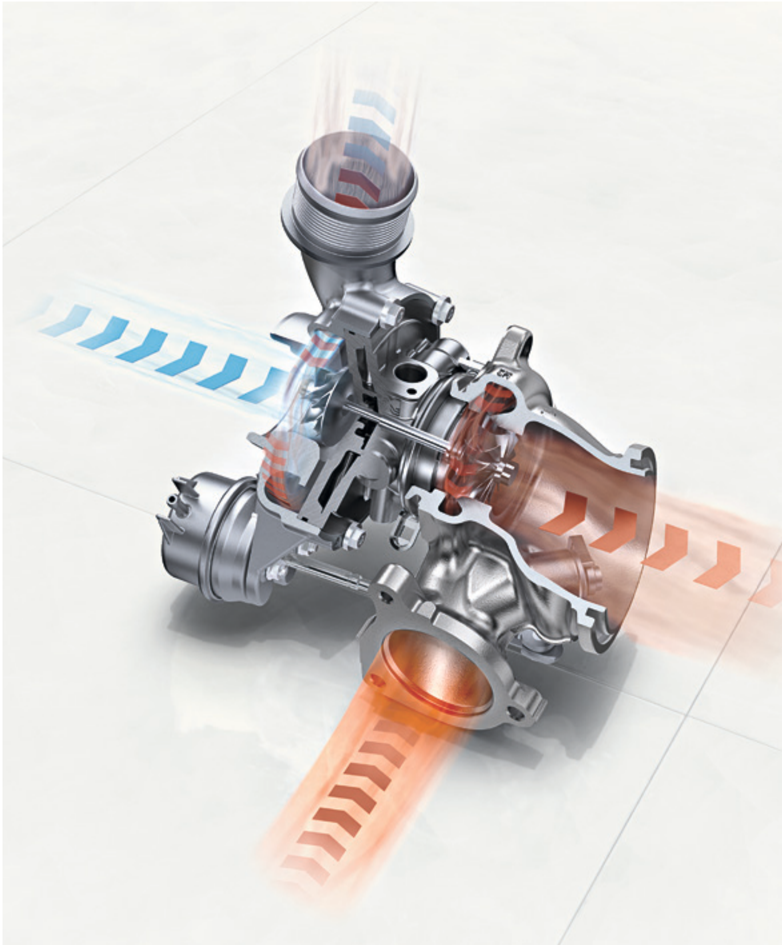
Porsche's turbo concept is notable for its combination of performance and efficiency: The turbo four-cylinder engine with PDK in the 718 Boxster consumes 6.9 l/100 km combined in the NEDC, and the 2.5-liter turbo four-cylinder with PDK in the 718 Boxster S makes do with 7.3 l/100 km.

The two variants of the new Porsche flat engine differ only in terms of displacement: In the standard engine, a conventional wastegate turbocharger forces additional air into the combustion chambers. The more powerful engine is ventilated by a charger with variable turbine geometry, which was previously available exclusively in the 911 Turbo. The special thing about the turbo four-cylinder in the Boxster S: An additional wastegate makes it possible to operate the turbocharger with adjustable guide blades at peak efficiency at all times by controlling the exhaust flow. The energy in the exhaust tract is thus optimally converted into propulsion power.

Turbo technology that acts like a naturally aspirated engine

In the tuning of the exhaust turbocharger, the Porsche developers paid special attention to achieving engine responsiveness comparable to that of a naturally aspirated engine. Among other things, this included a "pre-tensioning" of the turbocharger during sporty driving in the partial load range: The bypass valve is closed, the throttle valve is slightly opened and the ignition angles are dialed back. In this way, the current drive torque remains the same while the airflow through the engine and the boost pressure increase. If the driver then floors it, higher torque is immediately available thanks to the higher boost pressure. Even if the driver briefly eases off the pedal during full acceleration, the turbo engine retains the quick-reaction capabilities of a naturally aspirated engine. The throttle valve stays open; only the fuel injection is interrupted. Thus the boost pressure does not completely dissipate and the engine responds vigorously to renewed acceleration.

The turbocharger reacts in a comparable manner when the driver presses the Sport Response button, which is now located in the center of the program switch on the steering wheel in cars with the Sport Chrono package and PDK transmission, just as it is in the 911 models. Inspired by motor racing, the engine and transmission are thus primed for maximum responsiveness. Under partial loads, the wastegate of the turbocharger closes, enabling it to regenerate charge pressure significantly faster. The engine responds much more spontaneously to gas pedal commands and reaches its maximum power more quickly.

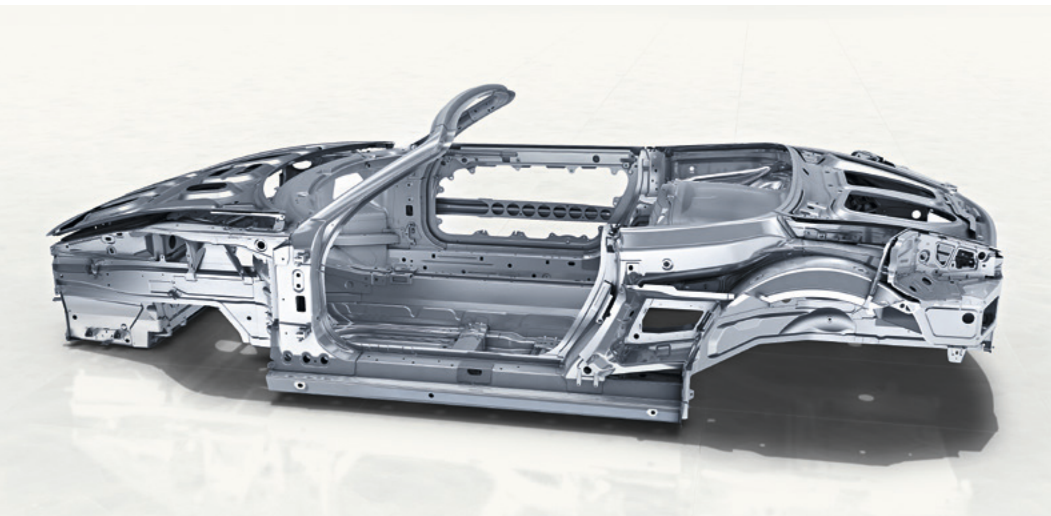


In the standard engine, a conventional wastegate turbocharger forces additional air into the combustion chambers.

The engines leverage technologies from the six-cylinder engines of the 911 to generate sporty performance and greater efficiency. The centrally positioned injector ensures excellent combustion, which has a direct impact on consumption and exhaust quality. A fuel pump supplies the direct gasoline injection system with system pressure of up to 250 bar. Moreover, the introduction of the adjustable outlet camshafts with stroke adjustment makes it possible to control the gas charge cycle even more precisely. On the intake end, Porsche continues to use the proven VarioCam Plus technology, which also variably adjusts both the stroke and opening times of the valves. ›

The chassis: ultimate precision for optimal driving dynamics

Converting engine power into driving dynamics has always been one of Porsche's core competencies. That the absolute power itself is not necessarily the key factor was amply proven by the 718 RSK and its several hundred victories. The chief advantage was its design as a mid-engine sports car. In those days, the chassis was largely based on that of the type 356. The front wheels were guided by the parallel trailing arms on a crank arm axle invented and patented by Ferdinand Porsche. One new development on the axle in the 718 RSK actually appeared in the name: While "RS" is the German acronym for "motor racing," the "K" refers to the front torsion bar springs, which were arranged in a shape that looked like a capital K lying on its back. This shape of torsion bar springs resulted in significantly improved responsiveness of the front axle. In the rear, the proven swing axle with coil springs and lowered pivot point does the job. The decisive advantage here was provided by the multi-tubular frame, whose high degree of stiffness enabled highly precise wheel control. The brake system, as was common in racing in those days, consisted of front duplex brakes and rear simplex brakes. Even back then, Porsche understood the importance of material combinations and used aluminum drums with an integrated iron friction ring.



Thanks to resolute lightweight design, the 718 Boxster achieves a power-to-weight ratio of 3.6 kilograms per hp.

In terms of driving dynamics, the roadsters of today follow in the tracks of their classic forebear, the 718. The completely re-tuned suspension further enhances the cornering performance of the mid-engine sports car. On the North Loop of the Nürburgring, calculations suggest that an optimally outfitted 718 Boxster S will be capable of cutting over 16 seconds off the lap time of its predecessor model.

The flat-four engine is positioned to create a nearly perfect weight distribution of 45:55 on the front and rear axles, respectively. The engine continues to be supported by two rear transmission mounts and now, in the front, by two hydraulic engine mounts with adjustable stiffness. The benefit for the driver: When idling, the driver enjoys optimal vibration comfort thanks to the decoupled engine mounts. During driving, by contrast, switching to a more rigid connection eliminates disruptive influences from the engine mass.

Further developed and stiffer Boxster chassis

In order to enhance precision and lateral stability along with the driving performance, numerous details in the rear axle area were modified. A new transverse strut reinforces the rear subframe, increasing transverse rigidity. Shock absorbers with larger piston and cylinder diameters also improve precise wheel control through their greater rigidity. The half-inch wider rear wheels enhance the side-force potential and thus, in conjunction with the newly developed tires, contribute significantly to improved cornering stability.

The re-tuned hydraulic vibration dampers as well as higher stabilizer and spring rates keep pitching and rolling motion to a minimum. With the conventional suspension, Porsche utilizes additional rebound buffer springs on the front axle. They reduce the lift on the front end when accelerating and the roll angle during dynamic cornering. This improves comfort as well: The coordination increases the solidity and enhances compression for smaller and larger surface irregularities. This enabled yet further improvement in the combination of comfort and performance.

The new roadsters also boast improved handling characteristics. With its roughly 10% more direct electro-mechanical steering set-up, the 718 Boxster is more agile and maneuverable both on the track and in everyday traffic. The engineers

took the lower-geared steering gear from the 911 Turbo and adapted it to the 718 Boxster.

As an option in the new models, there is now a PASM sports chassis available for the first time in addition to the PASM with a body lowered by 10 millimeters. The PASM with sports chassis option offers a 20-millimeter lowered body and significantly stiffer tuning in Sport mode.

Lightweight design: faster even with less power

3.6 kilograms per hp—at the most: One of the secrets to the success of the 718 RSK was its power-to-weight ratio. 148 hp paired with a weight empty of roughly 530 kilograms. At the end of the 1950s, that made the 550 the ultimate cornering artist. It was the result of consistent lightweight design. The load-bearing structure was a multi-tubular frame made of seamless tubing, even lighter than in the predecessor model, the 550 A, and with an exterior shell made of aluminum. The weight-shaving went into the tiniest details. The housing of the five-speed transmission, for example, was made of magnesium. The upshot: In spite of the small flat-four engines, the 718 took numerous overall victories, major triumphs over competitors with more powerful engines.

3.9 kilograms per hp: The 718 Boxster S with a manual transmission is close to the original—also thanks to lightweight design. The aluminum-steel design of today's roadster uses steel only where its use is indispensable. This is made possible by the use of current metal processing technologies in the automotive industry. The design utilizes die-cast aluminum, aluminum plate, magnesium and high-strength steel, custom-designed for the particular use in the body to ensure maximum stiffness while simultaneously minimizing the amount of material used. Over 46% of the new Boxster body-in-white is comprised of aluminum, including the front end, floor and rear end, doors and both luggage compartment lids. Dedicated lightweight design characterizes the interior as well; the cockpit mount is made of pressure-cast magnesium. The basic structure of the standard roll-over bars behind the seats is also made of aluminum, while the bars themselves are made of steel. With weights empty of between 1,335 and 1,385 kilograms—depending on the model and equipment—, the 718 Boxster is, in some cases significantly, the lightest sports car in its class.

With the round anniversary of the Boxster, in 2016 Porsche is celebrating a highly successful sports car—and the new generation of a typical Porsche, which once again is setting new standards in the combination of tradition and groundbreaking technology. ■

Variable Valve Drive

From the Concept to Series Approval

____ New vehicles are subject to ever more stringent limits in consumption cycles and emissions. At the same time, requirements in terms of engine performance, torque and smooth running at low engine speeds continue to rise. A key factor in resolving these conflicting objectives is played by the gas cycle. The development of an optimized, variable valve drive in particular shows potential.

By Andreas Eichenberg

The gas cycle and thus the design of the valve lift curve of a four-stroke engine are decisive for the fulfillment of the aforementioned requirements. Conventionally, the opening of gas exchange valves is designed for maximum engine performance. This definition, however, represents a compromise with regard to every other operating point in the engine control map. To achieve a better design in terms of the entire map, two or more valve lift curves tailored to the respective development focal points in the engine operating map are required. Porsche Engineering has therefore specialized in, among other things, the development and testing of trip cam systems that combine the advantages of different variable valve drive systems.

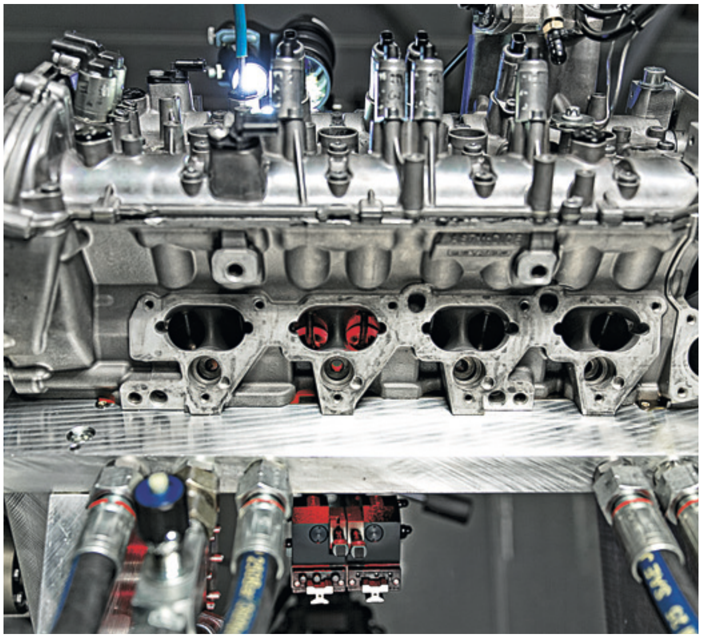
Valve drive systems in today's combustion engines are primarily focused on the transmission of the motion defined by the cam profile to the opening and closing gas exchange valve. The motion is mapped by various transmission elements. With these transmission elements, various principles are potentially in play. In current combustion engines, the most frequent elements are rocker arms with sliding or roller actuation. In the overall system, the valve spring provides a non-positive connection between the gas exchange valve and the rocker arm during the valve cycle. Taken together, these components are called the valve drive.

Valve drive development ranges from the concept, construction details, design and simulation to testing in the motored cylinder head and complete engine testing. By ensuring functionality at an early stage through simulations and on the mock-up test bench, development times for the engine as a whole can be kept to a minimum. Simulation-aided testing is increasingly common, and increasingly important in view of the rising complexity of variable, switchable valve drive systems.

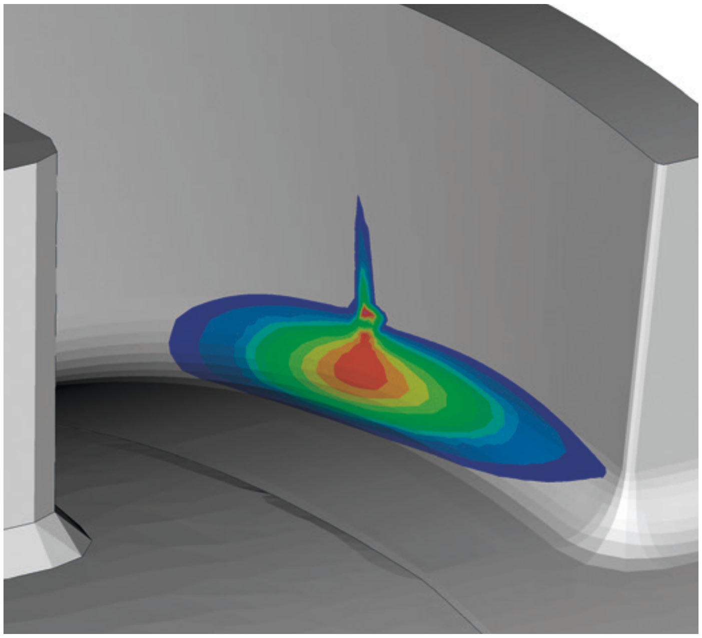
Different automobile manufacturers utilize variable valve drives. Trip cam systems are the most common type. Fully variable mechanical systems and hydraulically powered, mechanically switchable systems are also used. The diversity of different types of trip cam systems increases the complexity of the development, as do the requirements in terms of moving masses and shift speeds.

Effective and economical: trip cam systems

In spite of the variety of systems available on the market, the structure of a trip cam system is essentially always the same. A cam slide piece with multiple valve lift contours is pushed in a predefined groove—the shift guide—in the camshaft axis by a ram affixed to the cylinder head. This produces the axial sliding motion from the rotation of the camshaft. The ram is part of an electromagnetic actuator controlled by the engine control unit based on the engine control map. The cam slide piece is guided in the axial direction via an internal fundamental shaft.



Valve drive dynamics in the motored cylinder head



Result of structural calculation of shift guide parameters—service life

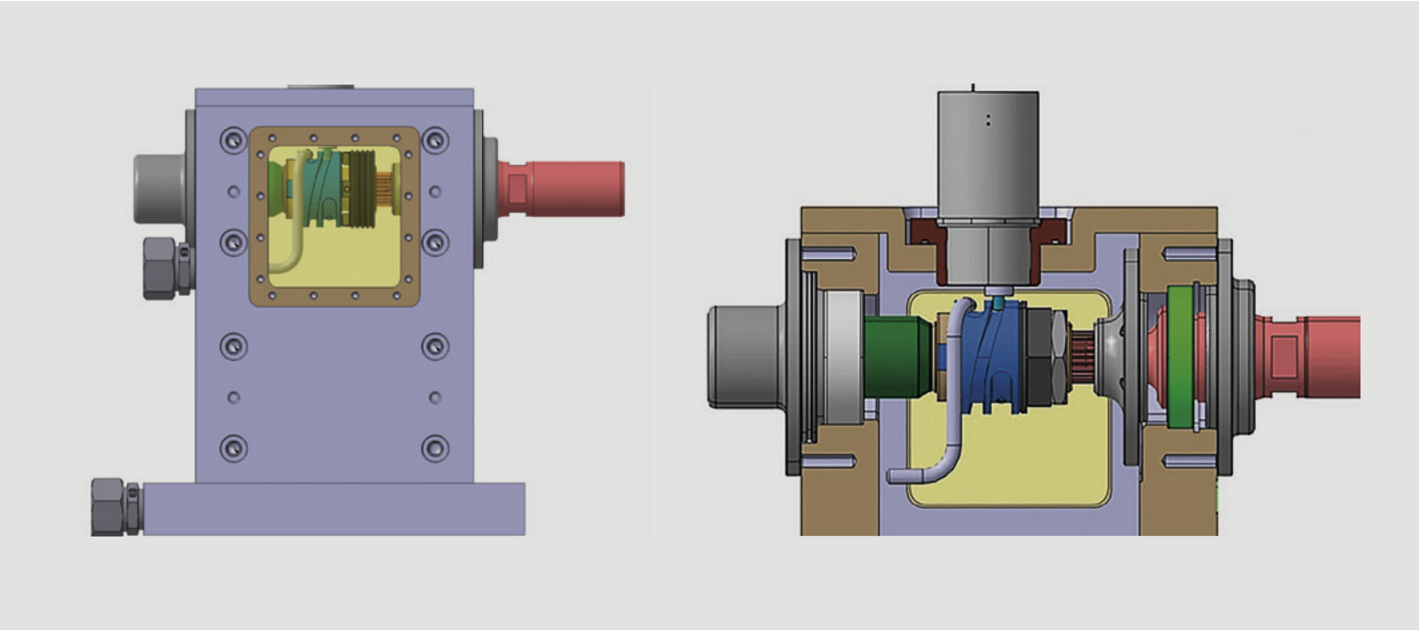
The advantages of this variable valve drive system are in the low impact on the dynamic opening and closing behavior of the gas exchange valves as well as in the low design and manufacturing complexity of the system. The dynamic properties of the valve drive depend on its moving mass. In trip cam systems, the moving mass is not increased due to the system. In contrast to other mechanically variable valve drive systems, a trip cam system has fewer components and their manufacture is simpler too, which directly impacts the overall complexity of the development.

Due to their design, trip cam systems present special challenges in the development process. Particularly noteworthy are the shift speed, the weight of the cam slide piece and the system tolerances that need to be mapped in the shift guide. Based on experience with conventional valve drive concepts, Porsche Engineering has established a modular process for the developers of such systems. The advantage: high flexibility and speed.

The foundation is the description of the requirements of the variable drive. In the concept phase, these requirements and conditions are implemented in a basic design. For a trip cam system, the primary issues are the bearing of the fundamental shaft and cam slide piece, the locking mechanism for the latter, the number of different cam profiles (which lead to two- or multi-level actuating mechanisms) and the design of the electromagnetic actuators. Apart from the design detailing, these points also influence the overall weight of the cam slide piece. As the heart of such a trip cam system, the shift guide is defined by the weight of the cam slide piece and the maximum attainable shift speed. The kinematic length of the shift guide is influenced by the position of the valve lift curves. Thus in the design phase, the displacement travel can be determined based on the disengaged base circle phases of the valve drive, and its course determined based on the acceleration.

In-house development: multibody simulation model

Based on Porsche Engineering's experience, a dynamic multibody simulation model (MBS model) was created. The model maps the dynamic influences on the displacement travel. These factors include the play between the actuator ram and shift guide as well as the rigidity of the bond between them, damping forces and the shift speeds. The results from the MBS model form the foundation for iterative modification of the acceleration profile of the shift guide. The focus here is on minimizing the load on the actuator ram and the shift guide in the form of Hertzian pressure and frictional forces in the actuator. Particular attention must be paid in this regard to the flank change within the shift guide during the ›



Set-up of the tribology test bench at Porsche Engineering

transition from acceleration to deceleration of the cam slide piece. The result of this iterative design process is a dynamically secured shift guide that is calculated to harmonize optimally with the framework conditions.

For the simulated loads, the shift guide parameters are adjusted in the CAD detailing. A particular focus here is on areas with low wall thicknesses, and optimal contact pattern distribution of the actuator ram on the guide flank. The shift guide parameters are confirmed in structural calculations using the finite-element method (FEM), among others. The structural calculations are also used in evaluating the contact conditions and material stresses. The areas with lower wall thicknesses are evaluated with regard to the changing loads using service life calculations. The detailed design generally concludes this theory-heavy development phase with a rapid-prototyping component as a visual sample.

Pre-testing ensures viability of materials and coatings

In pre-testing, individual components are examined. This is done at the earliest possible stage in the development process in order to allow the test results to be integrated into the development of the product without extraneous development cycles. The focus is on testing various material combinations and coating systems in the area of the material contact between the actuator ram and the guide flank. The pre-testing also includes an examination of the actuator switch time under the influence of various parameters. For example, the electromagnetic dead time and time-of-flight of the actuators for complete engine operation in the range from –20 °C to 120 °C with respect to the oil and component temperature is examined. The reproducibility of the lubrication conditions and the test conditions are critical here.

At Porsche Engineering, tribological tests are conducted on a test bench devised specifically for this purpose. The purpose of such tests is to examine the interaction of various surfaces in relative motion with regard to material characteristics and coating systems. The objective is to get a read on the viability of the selected tribological pairing in the shortest possible time.

The heart of the tribology test bench is the interchangeable slide piece on which the shift guide defined in the design phase is located. The interchangeable slide piece is driven by a splined fundamental shaft. In the shift guide, there is a permanent actuator ram mounted in an electromagnetic actuator. An oil injection nozzle within the test bench ensures ideal lubrication conditions. A housing shields the test chamber from the lubricating oil mist generated during operation.

The modular set-up of the test bench enables highly flexible use and rapid modifications of the components being tested. Pre-testing of trip cam systems may involve the examination of, for example, different DLC coatings (diamond-like carbon), changes to material pairings in the area of the shift guide and actuator ram, as well as various acceleration processes for the shift guide.

On the interchangeable slide piece, the shift guide takes the form of an endless groove. In conjunction with the actuator ram, the endless guide executes two opposing movements of the interchangeable slide piece per revolution. Thus with an appropriate shift speed, a large number of shift cycles can be carried out on the test bench in a short amount of time. The speed and mass of the interchangeable slide piece determine the loads on the actuator ram. The speed represents a compromise of the actuation frequency and thus the local heat input on the test components. Pre-testing concludes with an analysis of the run marks on the shift guide and actuator ram. The results are integrated directly into the development process—for instance component manufacturing.

Secure path to series production

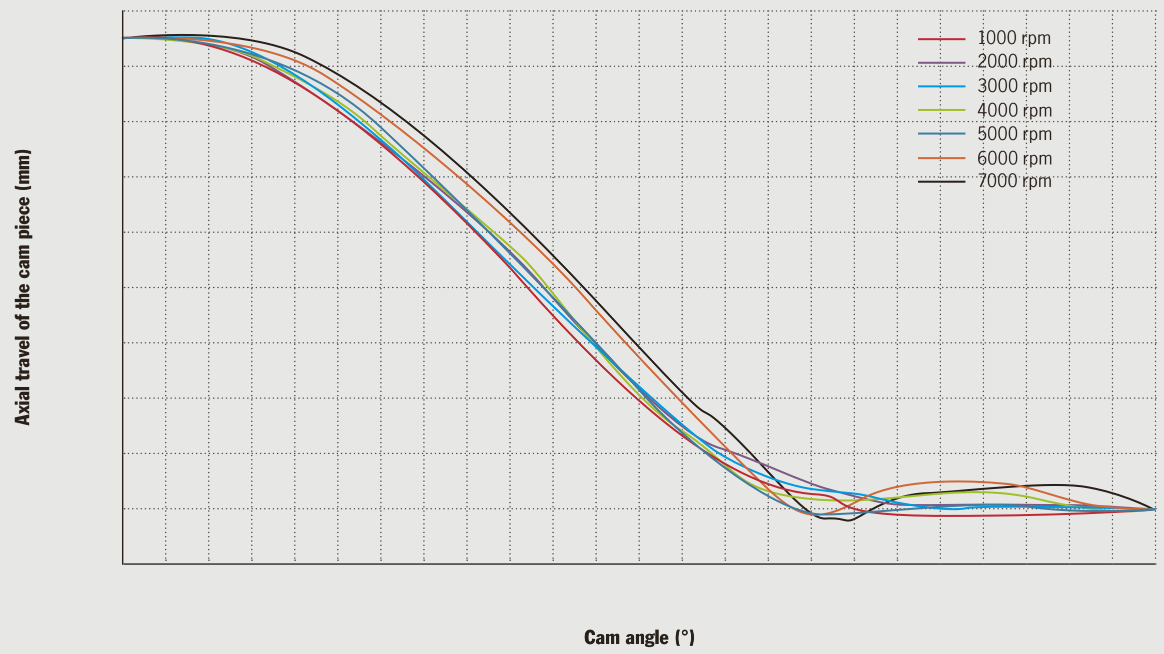
Due to the complexity and the requirements in terms of dimensional accuracy and surfaces of the components, production of the components of the trip cam system requires a high degree of precision. Porsche Engineering accompanies the implementation of such a system in the prototype phase, from heat treating and the individual processing steps to component measurement and quality control.

Functional and durability testing conclude the validation of the trip cam system. These tests are conducted under near-complete engine conditions on a cylinder head mock-up test bench. The test bench is a cylinder head with the original control assembly equipped with measuring technology. The drive power is supplied by a high-torque asynchronous machine. The connection between the electric machine and the stand-in crankshaft is provided by a torsionally stiff coupling with an integrated torque measurement flange that records the drive torques and thus the friction of the individual assemblies.

The focus of the testing of the trip cam system is on the functional dimensions of the displacement travel and the dynamic actuator ram forces. The displacement characteristic is measured using a magnetoresistive sensor and analyzed visually with the aid of a high-speed camera. To measure the actuator ram forces during the cam displacement, calibrated strain gauges are used in the area of the ram mount. The system records the measurement indicators for values from the camshaft angle to the maximum displacement speed. The dynamic effects in the measured values are analyzed to form a basis for the further development and approval of the trip cam system. The focus is on the initial contact of the actuator ram with the shift guide, the switching of the shift guide side from the acceleration flank to the deceleration flank of the cam slide piece and the movement of the latter towards its end position after its complete displacement travel.

Additional tests of torsional vibration and the displacement path of the cam slide piece depend on the selected bearing and valve drive concept. These measurements are generally required when negative influences on the dynamic opening and closing behavior of the gas exchange valves occur in complete engine operation. It remains important to prevent any ›

Interchangeable slide piece with endless guide



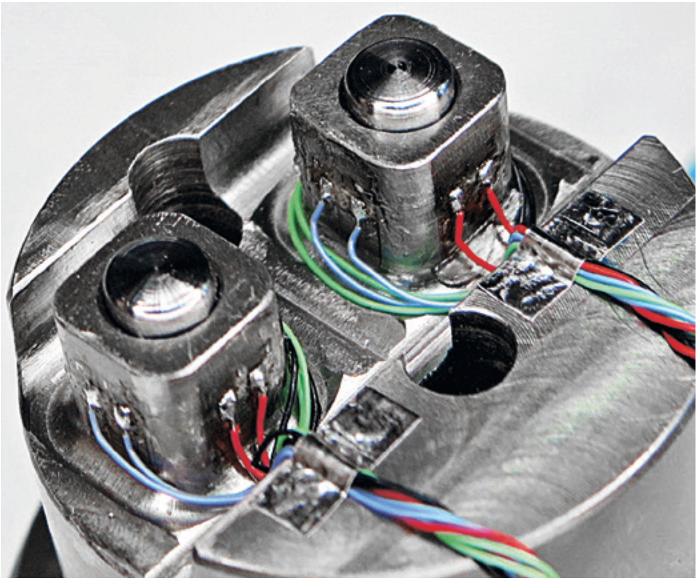
High-resolution measurement of the dynamic displacement travel

impact on the conventional valve motion by the trip cam system. To ensure proper functioning, the valve drive dynamics are tested on the cylinder head mock-up test bench or in the running complete engine. Functional testing ultimately concludes with a test of the rocker arm and mount element loads and measurement of the friction values of the variable valve drive system.

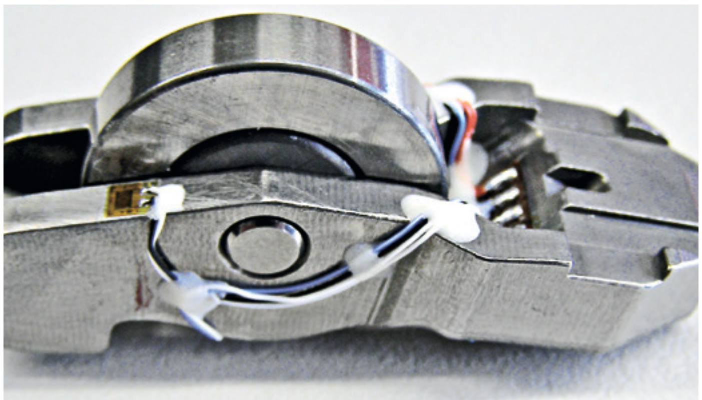
The trip cam system must demonstrate durability

After the functional validation, the trip cam system is subjected to endurance testing on the test bench. The testing of this subsystem is also conducted in the cylinder head in order to ensure efficient and rapid feedback for the complete engine development process. This involves automatic testing of realistic—e.g. highly dynamic—and synthetic speed profiles. The focus of synthetic speed profiles is to test a large number of shift cycles in a short amount of time on the test bench without neglecting realistic use conditions. The power supply to the actuators is triggered by a specially developed real-time operating system when the defined shift conditions occur. The emphasis here is on avoiding incorrect shifting. The intelligent shift logic developed for this is based on the recording of the axial and rotation angle-specific position of the cam slide piece. These measured values are recorded on the test bench by multiple sensors. The pilot control of the component-specific dead time and time-of-flight of the actuators is also mapped in the shift logic. This ensures that the actuator rams are only extended in the geometrically prescribed angle range.

During endurance testing, the running surfaces on the shift guide and actuator rams are regularly inspected. The history of the run marks is part of the comprehensive assessment



Strain gauge application: actuator ram force measurement



Strain gauge application: rocker arm load

following completion of the endurance shift testing. The data collected during the duration of endurance testing forms the foundation for the overall validation of the trip cam system. In such an endurance test, a variety of threshold states is tested in view of the desired target conditions. These threshold states relate to the component-specific dimensions and the functional conditions of the target system. Endurance testing is the foundation for the further functional development or approval of the trip cam system.

Summary

Early validation of subsystems of the combustion engine plays an increasingly important role in shortening the overall development duration. This requirement is reflected in the development process for trip cam systems. It is foreseeable that with the continuous development of variable valve drives, additional individual tasks will be added to the process. These include, for example, the prevention of incorrect shift states and the development of locking concepts. Porsche Engineering will continue to actively pursue and advance this trend towards multi-level development in these systems, both conceptually and in terms of design. ■

Lateral Thinking

____ Porsche Engineering's Interdisciplinary Qualification Program (IQP) for young professionals has established itself as a rich source of ideas for extraordinary development-related products. In cooperation with the Porsche Design Group, the fifth edition of the initiative led to the development of an extraordinary watch winder.

By Nadine Guhl

Exclusive products require expert development and craftsmanship. With these qualities in mind, the IQP program has already led to multiple collaborations between the Porsche Design Group and Porsche Engineering.

The Interdisciplinary Qualification Program (IQP)

The IQP is an 18-month personnel development program at Porsche Engineering aimed at young professionals with the goal of preparing them for the challenges and demanding responsibilities and situations they will face in their professional lives. The main component is a project independently conducted by the participants that focuses in particular on promoting interdisciplinary collaboration. In addition, the participants complete a 14-day internship outside of their own specialization (generally in a social area), take part in various interdisciplinary seminars and receive advice and support from a personal mentor. Through it all, there is a strong emphasis on cultivating a service mentality.

A watch winder for the Porsche Design Group

The team from the IQP young-professional development program decided to dedicate its efforts this time around to developing a watch winder for the presentation of the new watch collection from Porsche Design. Watch winders are used to wind automatic watches and thus keep them running. Aside from the convenience of having a wound-up watch, a watch winder also improves the lubrication of the movement and thus contributes to the durability of the watch itself.

The goal of the project was not to develop an ordinary watch winder, but rather one, like the watches themselves, whose impressive design and exceptional quality make it a "talking piece," in the lingo of the design world. The idea rests on Porsche Design's principle of establishing a thematic bridge between the technology in Porsche vehicles and the watches. The result is a gear wheel design reminiscent of a technical gearbox. Visually striking as a product, the technical implementation was nevertheless challenging.

Through a central drive mechanism, the watch winder winds up to five modules in which the watches are stored individually. The gear design in the drive mechanism and the modules is an extraordinary feature. The gear wheels fit into each other like in a technical gear mechanism and create the watch winder's characteristic circular motion. To create the prototype, the individual components were manufactured from plastic in the rapid-prototyping procedure. The drive mechanism is a small electric motor hidden in the drive wheel. ›

Prototype of a design watch winder that was recently developed for the Porsche Design Group as part of IQP.

Prototype of a design floor lamp based on an original 911 LED main headlight, developed by the 2013 IQP team.

The projects that make up the Interdisciplinary Qualification Program do not simply promote "lateral thinking," but actually demand it. Even the development of a watch winder required knowledge and experience from vehicle development in order to apply both elements to this technically complex product. Moreover, as the development activities were ongoing, it was necessary consistently to bear in mind and coordinate with the design and cost parameters of the project partner—a collaboration precisely analogous to the relationship between the customer and service provider in the automotive project business. From the original idea to the end product, the young professionals implemented the project independently.

Traditional collaboration

The best-known product that has emerged from the collaboration between the Porsche Design Group and Porsche Engineering and met with high market demand is the Porsche champagne cooler based on an original finned cylinder. Another IQP team developed a fully functional prototype for an extraordinary floor lamp based on an original 911 LED main headlight. Whether, and with what degree of success, the newly developed watch winder comes to the market for end customers remains to be seen.

"We're impressed over and over again by the dedication and passion the young professionals in the IQP program bring to their respective projects. With great imagination, technical expertise and lateral thinking, they've developed extraordinary products," says Frank Angelkötter, CFO Porsche Design Group. ■

The Porsche Classic Cooler. The 2010 IQP team developed this unusual champagne cooler based on an original finned cylinder.

IMPRINT

Porsche Engineering
MAGAZINE

ISSUE 1/2016

PUBLISHER
Porsche Engineering Group GmbH
Porschestrasse 911
71287 Weissach
Germany
Tel. +49 711 911 0
Fax +49 711 911 8 89 99
Internet: www.porsche-engineering.com

EDITOR-IN-CHIEF
Frederic Damköhler
EDITING | COORDINATION
Nadine Guhl
ADVERTISEMENT
Frederic Damköhler
DESIGN
VISCHER&BERNET, Stuttgart
TRANSLATION
RWS Group Deutschland GmbH, Berlin
PRINTING
Kraft Druck GmbH, Ettlingen

FSC
www.fsc.org
MIX
Paper from responsible sources
FSC® C020290

www.porsche-engineering.com

PORSCHE DESIGN
TIMEPIECES
911 GT3 RS fuel consumption [in l/100 km]:
urban 19.2 · extra-urban 8.9 · combined 12.7;
CO_2 emissions: combined 296 g/km
CHRONOTIMER SERIES 1 DEEP BLUE
Polished titanium chronograph with deep blue accents. A fusion of elegance and sportiness. Designed in Austria. Swiss Made.
SPORTY PERFORMANCE IN TITANIUM
Porsche Design – Men's Designer Sportswear and Accessories for the Global Business Traveller.
www.porsche-design.com