Porsche Engineering

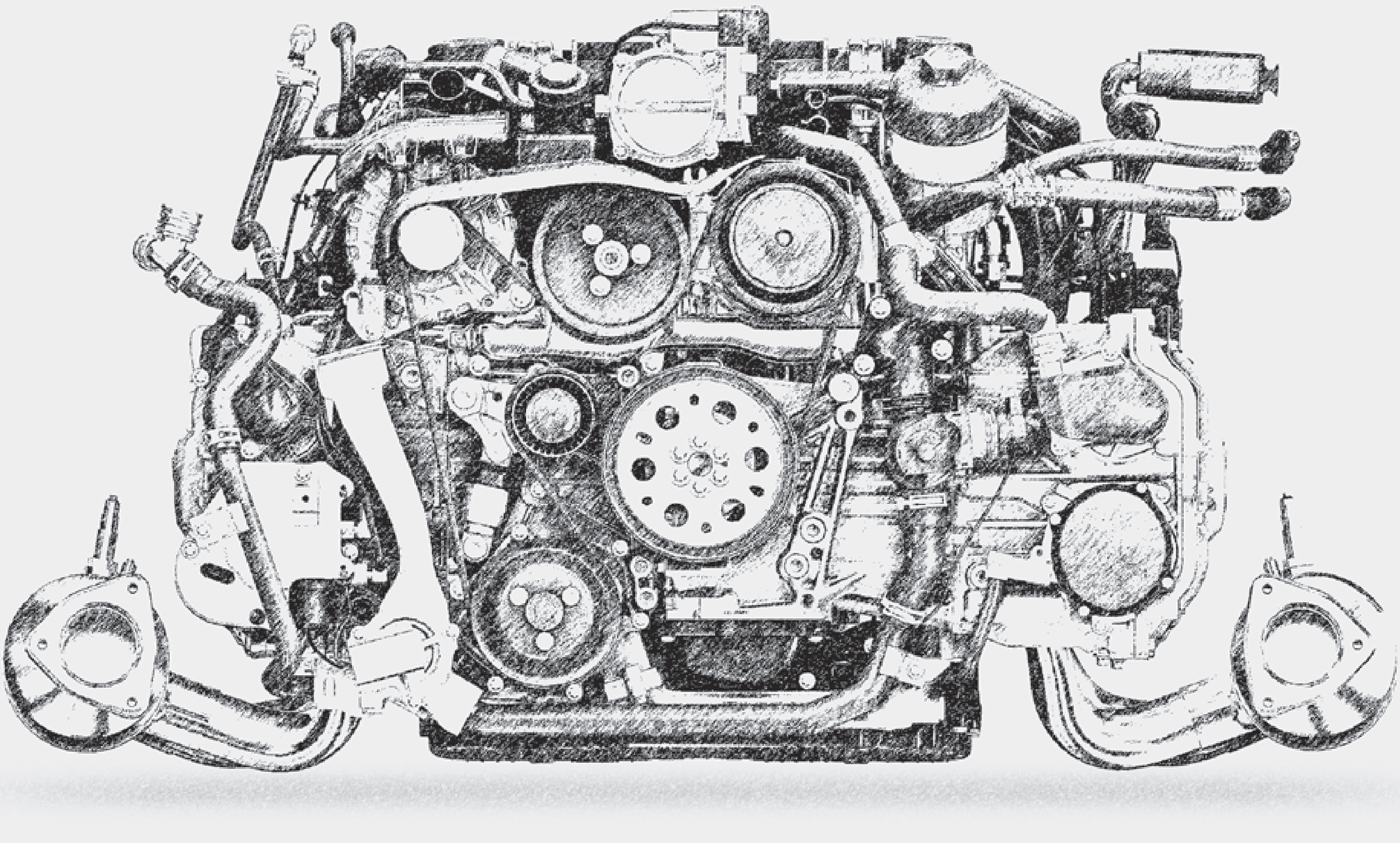
MAGAZINE

CUSTOMERS & MARKETS Scania and Porsche Engineering–a very special collaboration
PORSCHE UP CLOSE Master of curves: the new Cayman
ENGINEERING INSIGHTS More efficient software development through rapid control prototyping

ISSUE 1/2013

MULTIFACETED

Engine development for the future



www.porsche-engineering.com

Malte Radmann and Dirk Lappe,
Managing Directors of Porsche Engineering

Dear readers,

_____ Porsche. Engine. Two words that are inseparable. Looking at the example of the 911, we can see just what an extraordinary development an engine—in this case a flat-six engine—goes through in 50 years. Throughout the years and to this day, engine developers have asked themselves how much further the traditional combustion engine can be developed. In this issue, *Porsche Engineering Magazine* examines this ever-fascinating subject and shows that engine development has not reached the end of the road—not by any stretch of the imagination.

On the one hand, there is the indefatigable drive of our engineers, which inspires them to grapple with the technical challenges presented by the field with each new day. On the other hand, changing conditions such as CO_2 regulations, as well as evolving demand due to issues surrounding the social acceptance of vehicles and sports cars in particular, also influence our development work.

But we don't restrict ourselves exclusively to cars—we like to test our mettle in other areas as well. In this issue we take a look at our collaboration with the commercial vehicle manufacturer Scania.

You can also look forward to learning about some technical details from the development of the new Porsche Cayman as well as engineering insights about the "rapid control prototyping" method, which facilitates an efficient and flexible model-based software development process. Generally we always keep an eye on trends and technologies: learn more about current developments and challenges in the field of aerodynamics/thermal management as well as the continuous use of tolerance management as a preventive quality assurance method.

We hope you enjoy this issue
of Porsche Engineering Magazine.

About Porsche Engineering

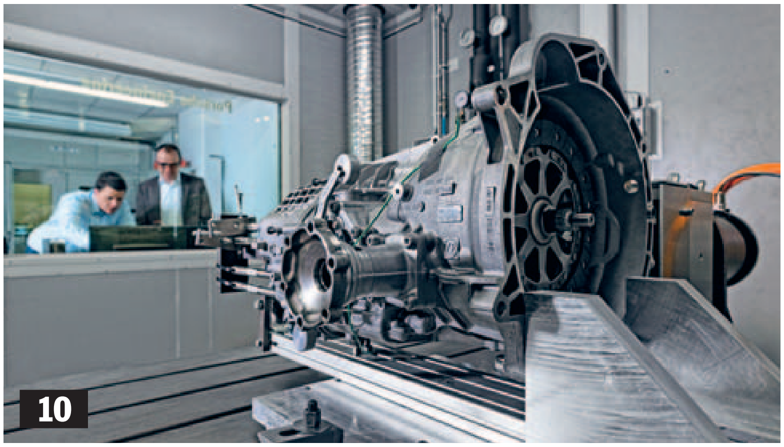
Creating forward-looking solutions was the standard set by Ferdinand Porsche when he started his design office in 1931. In doing so, he laid the foundation for today's engineering services by Porsche. We renew our commitment to that example with each new project that we carry out for our customers.

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.

30 CUSTOMERS & MARKETS

EVERYDAY EXTRAORDINARY

What happens when a commercial vehicle manufacturer works together with a sports car developer? Find out more in the customer interview with Scania.



911 (TYPE 991) Fuel consumption (combined): 12.4–8.2 l/100 km; CO_2 emissions: 289–194 g/km

CAYMAN Fuel consumption (combined): 8.8–7.7 l/100 km; CO_2 emissions: 206–180 g/km

News

INTEGRATION IN HIGH GEAR

___ Changes and improvements are steadily advancing the integration project at the Porsche Group's Nardò Technical Center in southern Italy. In addition to the long-term expansions and enhancements to the facilities and tracks, both major and minor changes are already evident. Appointment of a technical managing director for the Nardò Technical Center can be seen as yet another important milestone in the integration process. Edmund Sander, who has directed the drivetrain and suspension division at Porsche Engineering for many years, will be in charge of the technical divisions and provide strong support to Francesco Nobile, the Chairman of the Management Board, who heads the commercial divisions. The Nardò Technical Center will thus become an even more crucial resource for external customer projects connected with Porsche's engineering services than it already is today. ■

www.porsche-nardo.com

911 (TYPE 991) Fuel consumption (combined): 12.4–8.2 l/100 km; CO_2 emissions: 289–194 g/km

News

MOTIVATED EMPLOYEES FOR DEVELOPMENT PROJECTS

EMPLOYEE SURVEY

___ The high degree of motivation with which Porsche Engineering employees tackle demanding customer projects is a crucial factor in the success of *Porsche Intelligent Engineering*. A recent poll of employees at Porsche Engineering has confirmed the positive results of past surveys. Employees are very motivated and committed, and also view their work as meaningful, interesting, and varied. In comparison to the last survey the engineers' identification with the company has increased yet again. Porsche Engineering commissioned an independent company to carry out the survey—and the high rate of response is yet another indication of the participatory culture at the company. ■

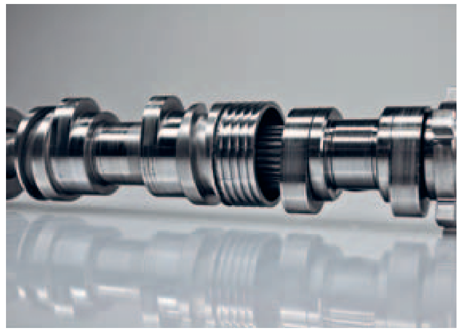
"VEHICLE ELECTRONICS" AND "TESTING EXPO"

TRADE FAIRS

___ Porsche Engineering is continuing to take part in conferences and trade fairs in 2013, in order to engage in direct dialogue with representatives of the automotive and other sectors. The broad range of electric/electronic solutions offered by Porsche's engineering service provider will be presented at a conference focusing on electronic systems for motor vehicles, which will be held by the Association of German Engineers (VDI) in Baden-Baden on October 16–17. The Nardò Technical Center participated in the Automotive Testing Expo Europe in Stuttgart on June 4–6 in order to present the facility and its full range of services related to development and testing. As always, Porsche Engineering can also be found at a large number of personnel and university fairs. More information is available at: www.porscheengineering.com/peg/en/jobs/events ■

MEASUREMENT PORTFOLIO EXPANDED

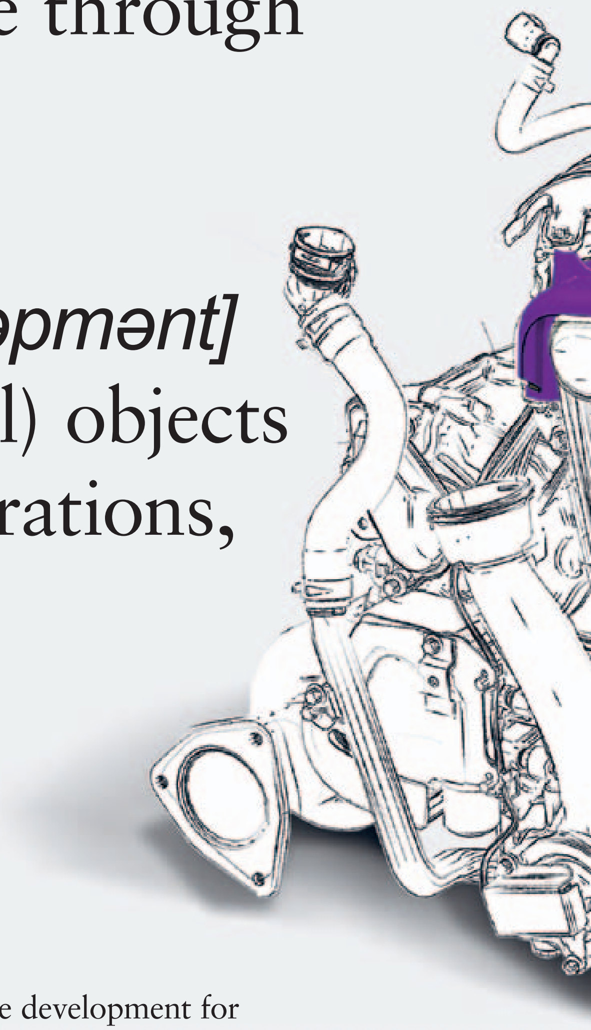
NEW PROCESS



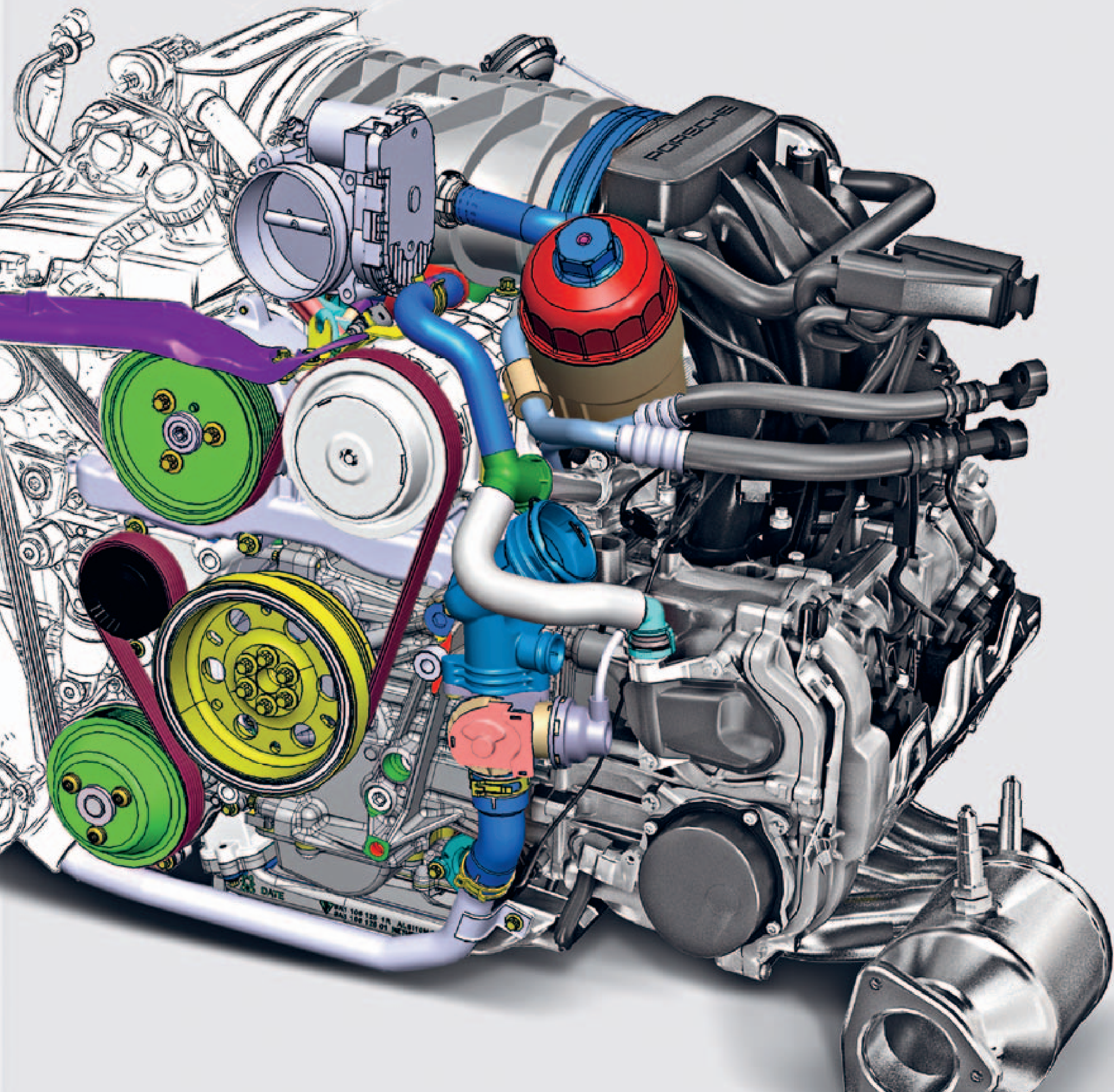
___ Porsche Engineering is expanding its measurement portfolio in the engine development sector with the addition of an innovative process for testing cylinder head designs. Ever higher efficiency and performance requirements are causing ever greater demands to be placed on valve drives and their design with respect to variability. Porsche Engineering is setting new standards here in analyzing the functions of multi-stage sliding cam systems that can optimize valve displacement for different operating conditions. In addition to conventional valve drive dynamics, analysis focuses on the sliding paths of individual cam segments. Measurement technology including high-resolution optics is used to register the sliding paths, and the actuating systems needed for the sliding processes are run by a real-time control system developed by the company itself. ■

En•gine *['ɛndʒən]* Machine that generates propulsive force through the conversion of energy.

De•vel•op•ment *[dɪ'vɛləpmənt]* The creation of (technical) objects through directed considerations, trials and designs.



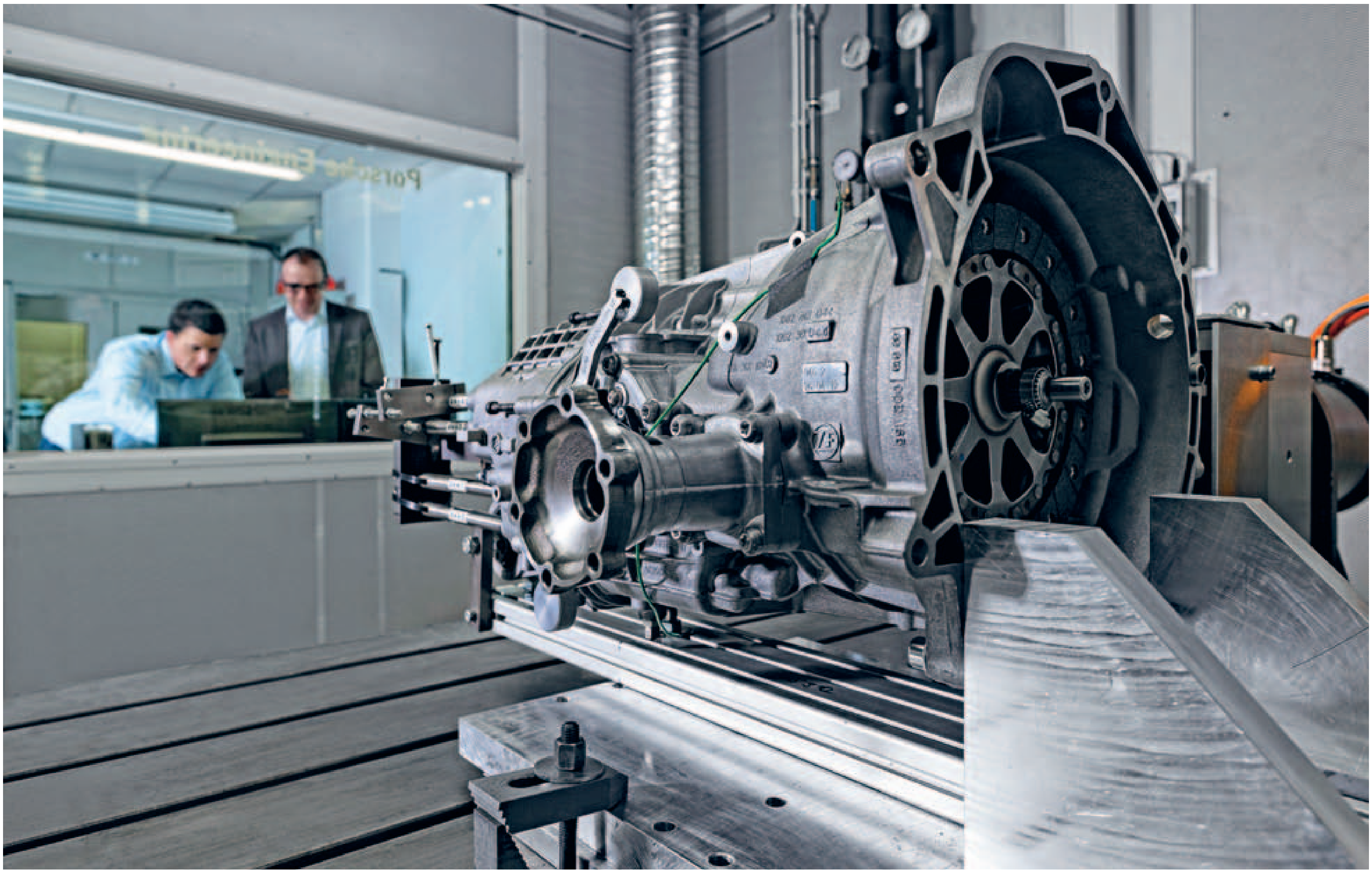
Two words—one passion. Especially when combined. Engine development for the future is one of the main tasks of the engineers at Porsche Engineering. One approach is downsizing—reducing fuel consumption without having to forgo top performance. Not just development know-how, but also comprehensive testing equipment is necessary to meet the mobility challenges of the future. Where will the journey take us? Klaus Fuoss, head of engine development at Porsche Engineering, talks about the future of the combustion engine.


PORSCHE

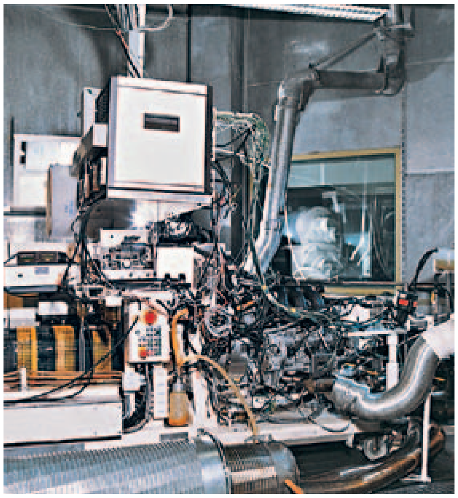
Endurance Testing: Practice

___ Developments only provide added value when they have passed real-life testing. Testing within engine developments is therefore extremely important for a wide variety of customer projects.

By Dr. Matthias Bach, Johannes Wüst, and Robert Kerres
Photos: Jörg Eberl, Gabriele Torsello, archive



Testing at the Weissach Development Center: View of the engine acoustic chamber (left) and an engine on a test bench (right)



Porsche has always been at the forefront of trends and technologies in the area of engine development—both for its own sports cars and projects for external customers. But only when the theory has been confirmed in practice do the true benefits for the customer come through.

A broad spectrum of engine test benches

To efficiently test the very different types of engines, Porsche has a wide range of different test benches. Continuous investment ensures that all Porsche locations always have state-of-the-art technology to meet the demands of increasing product complexity and changing legal frameworks, which also place more stringent requirements on engine testing and the test benches required for it. From small test benches for testing components and systems to standard engine test benches and high-performance test benches used for motor racing purposes, Porsche has everything centrally located at a single site. It is possible to test the various drive variants, from front- and rear-wheel drive to all-wheel drive engines. The infrastructure is also in place for efficient testing of hybrid and electric motors.

Diverse environments and short distances

To simulate all of the different environmental conditions that an engine can be exposed to, the range of testing capabilities includes the engine climate pressure chamber and the dynamic high-performance powertrain test bench, among others. These facilities enable simulation of different temperatures and pressures to ensure that the engines can withstand a vast array of environmental conditions. In addition to the various test benches and other testing capabilities, another important factor is the close proximity to the specific departments and other areas and workshops. Short communication paths ensure direct exchange of expertise and knowledge.

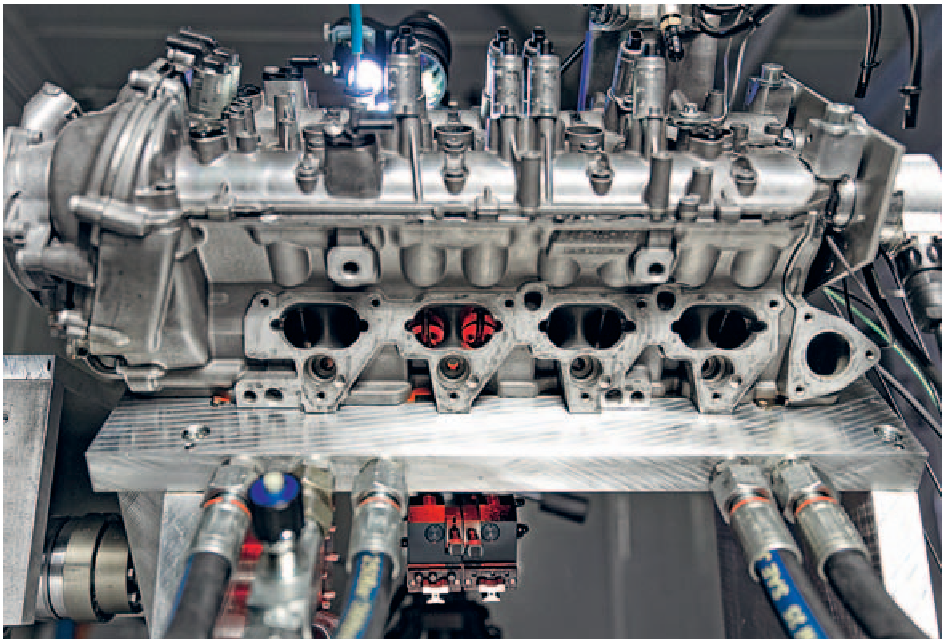
Customer-specific and multifunctional

Porsche Engineering also uses the test benches to conduct customer projects in a specific and efficient manner. The individual component test benches in particular offer the opportunity to accommodate the requests of customers not only from the automotive industry but also other sectors.

As the requirements for test equipment in development for external customers can vary widely from one project to another, the test facility itself must be designed with the greatest degree of variability in mind. To meet that challenge, the test facility is equipped for multifunctional use and is extremely flexible. This makes it possible to execute projects from different technological fields with great efficiency. ›

Porsche measurement technology

To record measured values for test objects, all test benches utilize Porsche-developed measurement technology (PMT), the fifth generation of which is currently being rolled out. This makes it possible to employ any given combination of different measurement modules for pressures, temperatures, voltages, and other variables. The measurement modules themselves are mobile and can also be used for measurements in the vehicle. Maintenance and calibration tasks are executed centrally at the Development Center in Weissach.



The Laser Doppler vibrometer measures lift and speed.

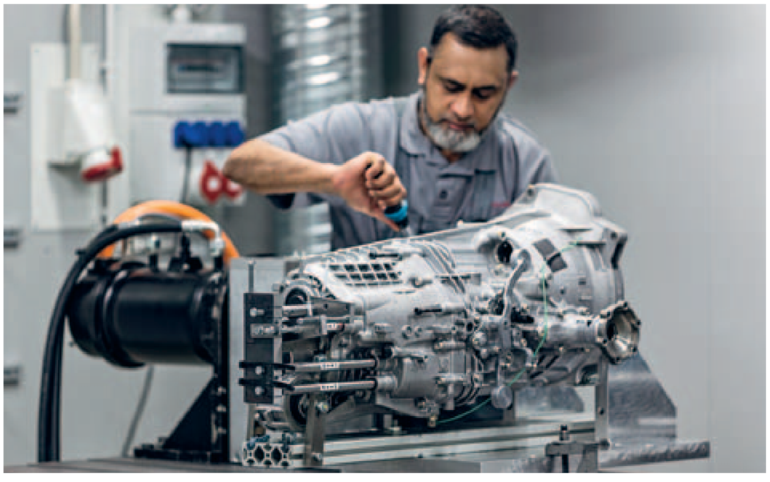
Intelligent test bench control

The test bench control is capable of simulating motor functions of control units that will be implemented in series ECUs (Engine Control Units) years later. One example is the variable valve-lift device, which controls valve-lift switching on engines in real time and with a crankshaft angle resolution of less than one degree.

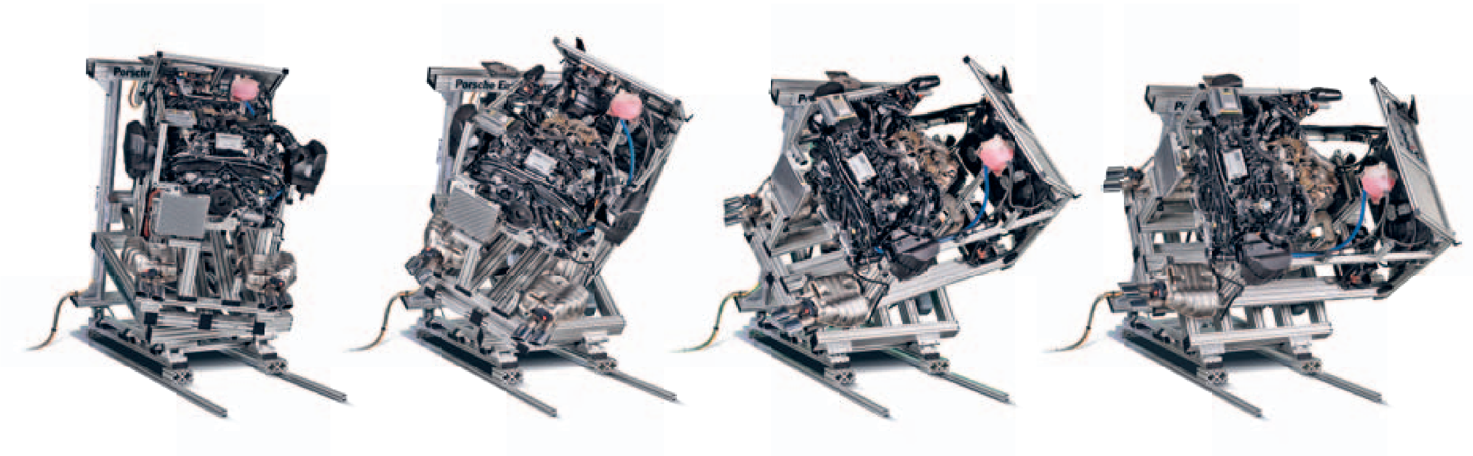
With these highly dynamic applications, extremely fast measurement of the test object is of the essence: mechanical defects or malfunctions must be detected without delay. Porsche Engineering has developed monitoring functions for some parameters that detect malfunctions within a five-degree crankshaft angle, trigger an emergency stop, and thus minimize any follow-on damages.

Dynamic valve drive measurement

To efficiently measure the dynamic characteristics of valve drive components, Porsche Engineering uses a test bench for taking measurements on mock-up cylinder heads. The cylinder head along with the control assembly is driven by a powerful asynchronous motor. A Laser Doppler vibrometer measures the lift and the speed of the valves. Processing and evaluating the values recorded at sampling rates of up to 400,000 Hertz makes it possible to draw conclusions about maximum permissible engine speeds, acoustic development, wear, and loads on components. Other parameters such as oil pressures, temperatures, torsional vibration, as well as signals from components applied with strain gauges are also used.



A transmission is mounted on the test bench.



The tilt test bench enables biaxial rotation of up to 60 degrees in any direction.

High-speed analyses

In many test applications, high-speed video cameras are used. This system makes it possible to visualize dynamic effects such as the oscillation forms of chains, valve springs, or the axial movements of cam segments in variable valve trains and later analyze them with image processing software.

Thanks to the modular structure of the test bench, in addition to valve drive measurements it is also possible to measure friction performance parameters on motored engines, engine components, or transmissions. Here high-precision torque flanges and oil conditioning with a very high control precision are used.

Hybrid and electric motors

The regenerative capability of the asynchronous motor in conjunction with a mobile 60 kW DC power supply also enables testing of electric drives such as belt alternator starters, for which the important breakaway torque at zero rpm as well as the efficiency in generation mode is determined.

In light of the rising hybridization and electrification of vehicles, the battery simulation systems required for efficient testing are already in use. There is also a 250 kW DC power supply available that provides the electric motors with the required power or feeds the generated electricity back into the grid when working in generator mode. To condition the electric motor and associated power electronics, a conditioning device that can test both systems separately at different temperatures between –40 degrees Celsius and +120 degrees Celsius is used. To determine the efficiency of test objects, an electrical power measurement device is utilized.

Tilt test bench

To simulate cornering maneuvers or braking and accelerating, engines can be mounted on a tilt test bench and tested to maximum engine speeds tilted up to 60 degrees over horizontal in all directions. The tilt test bench itself is attached to an air-suspension test bed frame with a leveling system, which in its lowered position is covered by plates and thus enables a level surface. In these tilting tests, the quality of oil aeration measurements is given particular attention.

Measurement of industrial engines

In testing industrial engines, thermodynamic measurement plays an important role. Engines for emergency generators, lawn mowers, or manually operated forestry equipment require a special type of testing that impacts the preparation ›

ADA test bench for testing exhaust emissions

of the test benches and the measuring procedure. The displacement can range from 25 cm³ to roughly 500 cm³. Eddy current brakes are used for the measurement of engine torque, while fuel consumption is measured gravimetrically.

Exhaust sensors

Exhaust gas measurement systems are in place to analyze exhaust gas. These systems extract very small sample amounts from the test object to avoid impacting the gas charge cycle, particularly in the case of 2-stroke engines.

To ensure that engine developments also fulfill customer-specific and legal requirements with regard to exhaust gas and emissions, more precise exhaust gas sensors can be utilized. In the Porsche Engineering center for environmental protection, vehicles are subjected to comprehensive emissions testing. In this regard Porsche has engaged in a long-standing collaboration with the Abgaszentrum der Automobilindustrie (ADA), the German exhaust emissions center for the automotive industry, for which Porsche operates special test benches. These include a hydraulic shock test bench with which protective tubes from AFR (Air Fuel Ratio) and NOx sensors are analyzed, as well as a test bench for the evaluation of particle sensors.

Challenges are welcome

The special thing about the Porsche engine testing facility is its wide applicability: both in terms of capability and flexible structure, it has all the prerequisites for efficient testing. The flexible design of the test benches and the fast configurability of the measurement technology make it possible to implement a vast range of tests, either for sports cars or other challenges. And when the development has proven its success in testing, there's just one more thing: the first test drive on the track …

911 (TYPE 991) Fuel consumption (combined): 12.4–8.2 l/100 km; CO_2 emissions: 289–194 g/km

… TIME FOR THE TRACK!

The Nardò Technical Center in southern Italy, which was acquired by Porsche in April 2012, offers ideal conditions for engine testing on the track and other purposes. Due to the special climatic conditions, standard tests (for example of the oil circuit, engine ventilation, or engine cooling) in stationary and dynamic driving modes can be carried out year-round. The proving ground enables the execution of comprehensive endurance drives as well as testing in extreme conditions. In particular in summer when extreme temperatures predominate in Apulia, the developments are pushed to the limit. And application testing of conditions such as high-speed scenarios, checking the basic engine application, the knock control dynamics test, and on-board diagnosis are all possible year-round at Nardò. Everything needed for special measurements in the vehicle, torque and torsional vibration measurements, and no-contact measurement of the exhaust valve temperature are on hand at the facility as well. Once a test object has withstood testing in Nardò as well, the end of the development process and ultimately its debut on the road are well within sight. ■

DOWNSIZING

_____ High specific power, a wide speed range with maximum torque and good transient behavior—these are the main characteristics that distinguish modern downsizing engines. In the future it will be necessary to reduce the fuel enrichment in order to achieve further fuel savings in customer-relevant operation. The engineers at Porsche Engineering are conducting various simulation studies in order to reduce fuel consumption without any loss of maximum vehicle performance.

By Eric Jacobs, Vincenzo Bevilacqua, and Gerd Grauli

911 (TYPE 991) Fuel consumption (combined): 12.4–8.2 l/100 km; CO_2 emissions: 289–194 g/km

Throughout the more than 35-year history of Porsche turbo vehicles, Porsche development engineers have been able to use various technologies (such as the optimization of the gas exchange using VarioCam Plus technology and introducing direct fuel injection) to double the engine power and the maximum torque while reducing fuel consumption significantly.

Downsizing in engine development

For quite a while now, Porsche Engineering has focused on developing engines with lower fuel consumption and increased efficiency. Reducing the displacement in spark ignition (SI) engines is an effective option to increase efficiency. In particular, this trend can be observed in the engines currently available on the market.

As engine load increases, there is a reduction in the pumping losses and in the percentage of friction. An analysis of state-of-the-art engines shows that if the driving dynamics and power remain constant, the displacement can be reduced by around 25 percent to enable fuel savings of around 20 percent. The goals of current engine developments are improving the transient behavior in combination with high engine power, a wide speed range with maximum torque, a reduction in fuel consumption in accordance with the New European Driving Cycle (NEDC), and in customer-relevant operation.

The difficulty

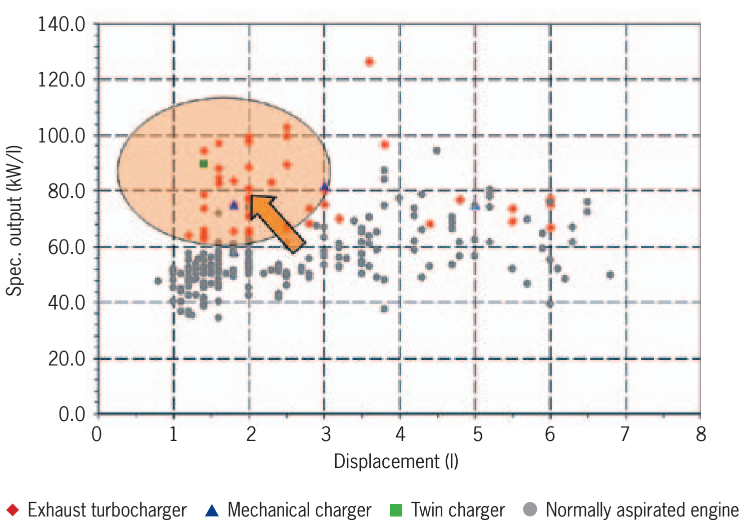
The requirements for charged SI engines lead to conflicting goals when laying out exhaust turbochargers. On the one hand, a larger exhaust turbocharger is meant to achieve a high output, while on the other hand the maximum torque should be reached even at low engine speeds without creating the impression of a turbo lag.

Small turbochargers are necessary to achieve an early, dynamic response. They create higher exhaust gas back pressure within the defined power range. The increased tendency to knocking in turbocharged engines due to the increased temperature and pressure values in the combustion chamber is further increased by the larger residual gas content. In consequence, there is a later ignition timing necessary, resulting in an increased exhaust gas temperature.

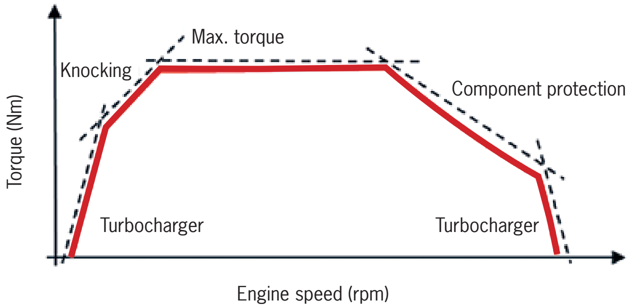
Knocking and the component temperature limits define the line of turbocharging. To ease these limitations, fuel enrichment has become an established practice in modern, turbocharged engines.

For high engine loads, and for vehicles with high rolling resistance, the benefits of an increased downsizing level are reduced due to earlier and more intensive fuel enrichment. In a customer-oriented driving profile, the positive effect of ›

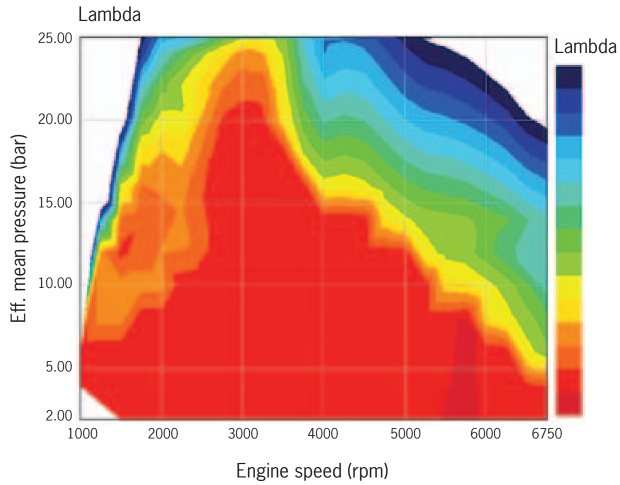
Market overview for current SI engines



Due to engine downsizing, high specific output is possible with reduced displacement.



Limitations of single-step exhaust turbocharging



Lambda engine characteristic map of a 1.6-liter turbo engine with mechanical charger

the higher downsizing level can even be reversed. Increasing the efficiency requires new technologies for expanding the area with an optimal air-fuel ratio.

The simulation model

The reference engine used is a 6-cylinder 2.9 liter normally aspirated engine with an output of 195 kW and maximum torque of 300 Nm. By means of the 1D gas exchange simulations, this engine is compared with a turbocharged 3-cylinder engine with 1.6-liter displacement. With turbocharging, the same power output can be achieved. To improve the transient behavior at low engine speeds, a mechanically driven supercharger is used whose characteristics are analyzed in various driving maneuvers using a coupled vehicle-engine simulation model. It is possible to reduce the fuel consumption in the NEDC by up to 27 percent while keeping the same driving dynamics.

In driving cycles with higher load cycles, the negative effect of the earlier and more intensive fuel enrichment becomes obvious. For example, in customer cycle A—which corresponds to a cross-country profile—the benefit is reduced to 14 percent. In customer cycle B, with higher load cycles, the fuel savings are only 9 percent. The use of components resistant to high temperatures, a cooled exhaust manifold, cooled inert-gas recirculation, and water injection is intended to reduce the fuel enrichment to protect components and avoid knocking.

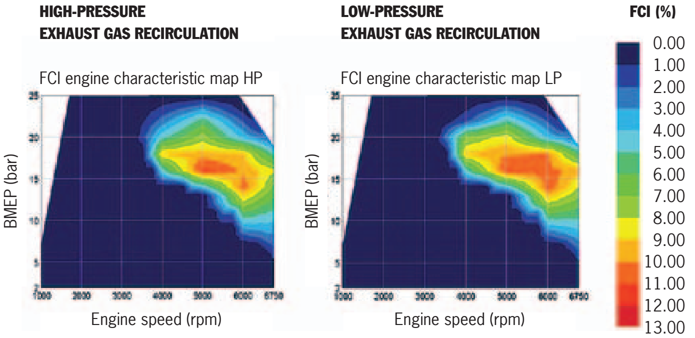
Cooled exhaust gas recirculation

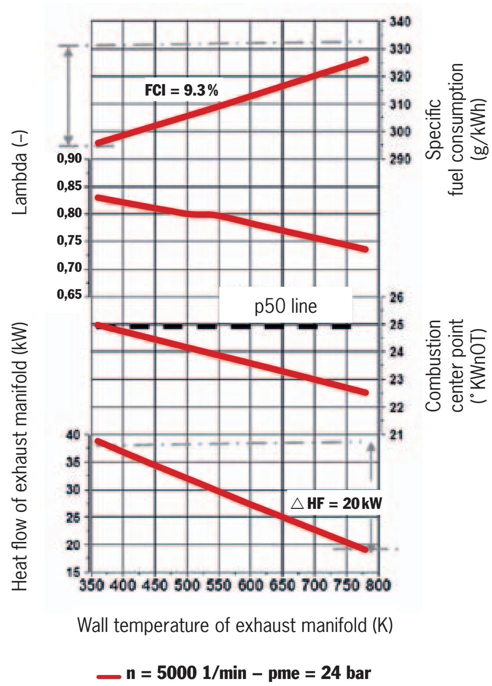
Cooled exhaust gas recirculation is a standard-production application for diesel engines. In the simulation carried out, two different concepts are analyzed. With low-pressure exhaust gas recirculation (LP EGR), the exhaust gas is extracted after the turbine wheel and reintroduced ahead of the compressor wheel. With high-pressure exhaust gas recirculation (HP EGR), the exhaust gas is extracted before the turbine wheel and reintroduced after the compressor wheel.

Using low-pressure exhaust gas recirculation has slight advantages compared to high-pressure exhaust gas recirculation. Overall, both concepts can achieve maximum fuel consumption savings of 12 percent for the engine used. However, the knocking tendency cannot be reduced using cooled inert-gas recirculation. ›

Analysis shows that for current engines, assuming that the driving dynamics and output are unchanged, it is possible to reduce the displacement by around 25 percent. As a result, fuel consumption savings of around 20 percent can be achieved.

Fuel consumption potential through cooled exhaust gas recirculation and cooled exhaust manifold





Fuel consumption improvements (FCI) through cooled exhaust gas recirculation

Potential of a cooled exhaust manifold

Cooled exhaust manifold

A cooled exhaust manifold is used in a number of current turbocharged SI engines. Simulations with the turbocharged 1.6-liter engine show that it is possible to reduce the fuel enrichment. However, complete avoidance of fuel enrichment would be difficult as the manifold would have to dissipate very significant heat flows. Extending the optimal air-fuel ratio area results in recognizable fuel savings. But due to the reduced internal cooling, it is necessary to move the ignition timing to a later point due to the increased knocking tendency causing an increased exhaust gas temperature. Another disadvantage: the engine efficiency loss must be compensated with increased charge pressure resulting in higher turbocharger speed, in order to generate the same engine power. In the lower speed range it is not possible to reduce the knocking tendency by using this technology.

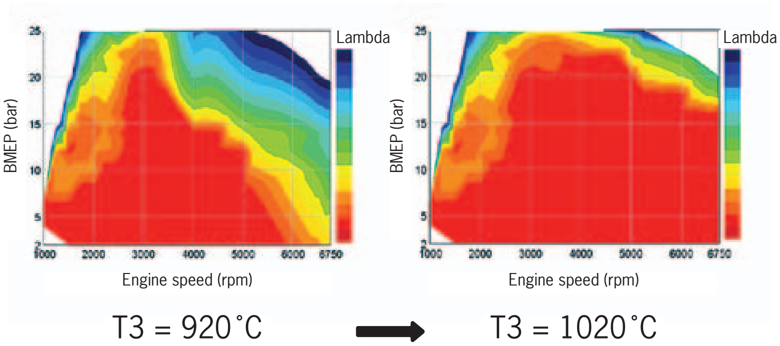
High-temperature materials

Materials resistant to high temperatures are series-production features in turbocharged SI engines. This technology allows higher exhaust gas temperatures. Therefore, the fuel enrichment can be reduced in the simulation, but cannot be avoided completely. As with the cooled exhaust manifold, there are no benefits for the knocking tendency in the lower engine speed range with high loads. The difficulty of reduced internal cooling also occurs with this system. The shift of the ignition timing also requires increased charge pressure by means of an increased turbocharger speed to compensate for the lower engine efficiency. Using high-temperature materials enables the optimal air-fuel ratio to be extended, but—as with the cooled exhaust manifold—it leads indirectly to lowered combustion efficiency.

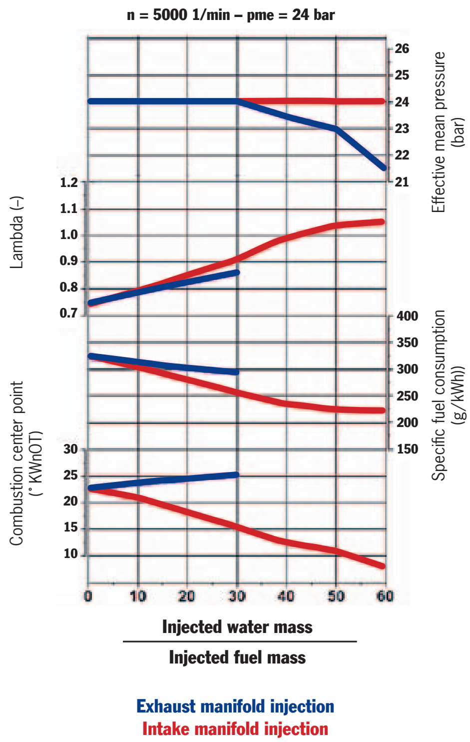
Water injection

Using water injection is familiar from motor sports, but it is not currently a series production feature of a turbocharged engine. It is possible to introduce water at various points into the turbocharged engine system.

In the simulation model, the introduction of water into both the intake manifold and exhaust manifold can be analyzed. The latter reduces the fuel enrichment required, but cannot completely prevent it in the simulated engine. Additionally, with this position the need for water is increased. The reduced internal cooling results in the same disadvantages as arise when using a cooled exhaust manifold or high-temperature materials. Because of the later ignition timing, *Higher exhaust gas temperatures are made possible by high-temperature materials. The technology of water injection—familiar from motor sports—enables further fuel consumption savings.*



Characteristic lambda map with and without high-temperature materials



Potential of water injection

due to the increased knocking tendency the turbocharger speed comes closer to its speed limit and there is an increase in the exhaust gas pressure.

In the case of water injection into the intake manifold, a stoichiometric air-fuel ratio can be used in the entire application area. In contrast to the other technologies analyzed, the engine efficiency can be increased due to an optimal ignition timing. This applies to both the knocking-sensitive area at low engine speed range and to full loads at high engine speed ranges. The effect of achieving the best possible combustion leads to a reduction of turbocharger load. As a result, both the turbocharger speed and the exhaust gas counter-pressure are lowered. Along with the enrichment being avoided, the optimal combustion center point enables high fuel consumption savings.

Conclusion

The use of high-temperature materials and a cooled exhaust manifold, as well as the recirculation of cooled exhaust gas, do not make it possible to reduce the knocking tendency of the engine. The advantage of high-temperature materials and a cooled exhaust manifold is that these technologies have already been implemented and proven in series production, and currently provide a good and simple option for reducing the fuel enrichment requirement in customer-relevant driving cycles.

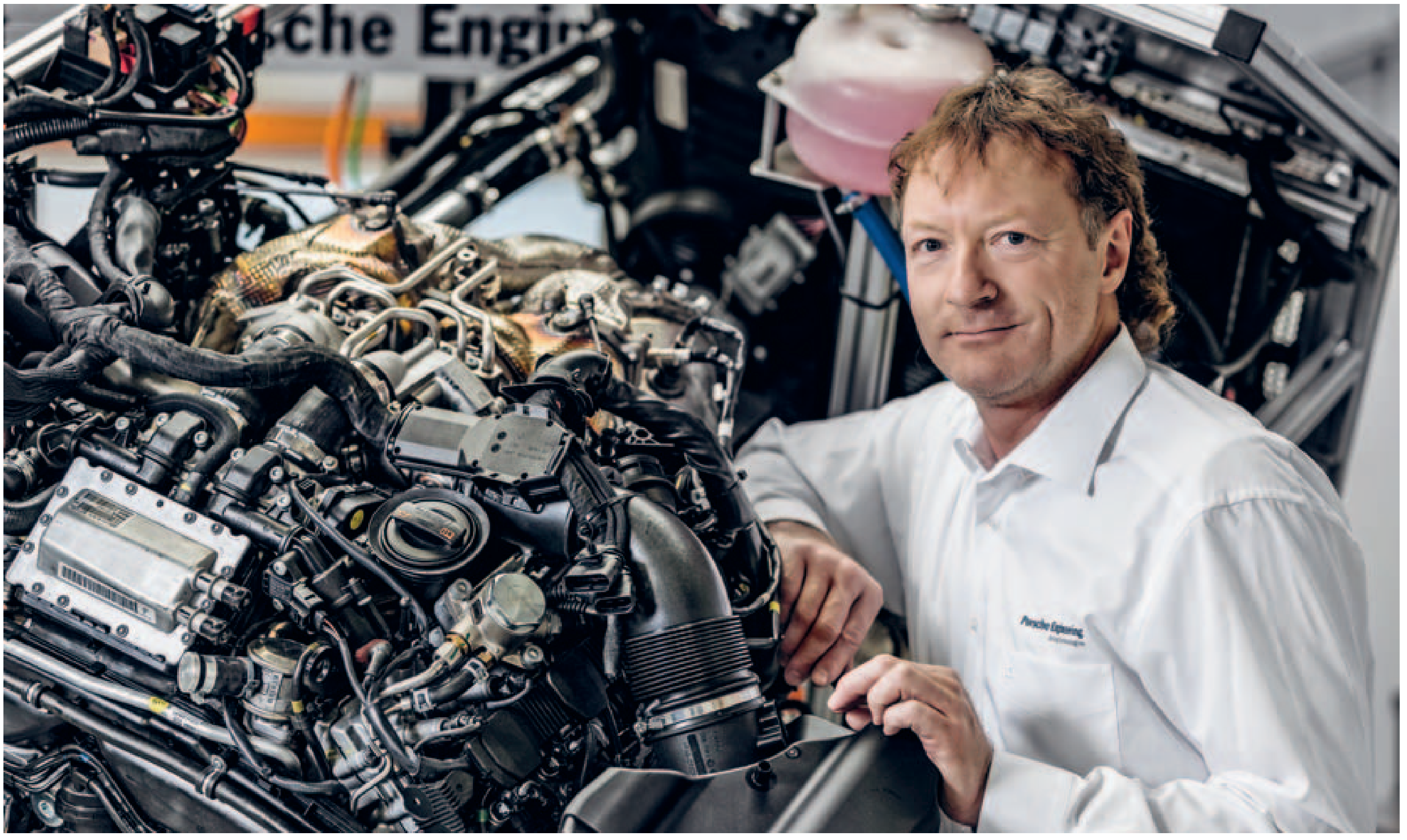
The technology of water injection into the intake manifold provides significant potential. This technology can use a stoichiometric air-fuel ratio in the entire operating area and an optimal ignition timing to increase the efficiency of the engine. In addition to a further reduction in fuel consumption, this effect also reduces the compression work so that the engine displacement can be further reduced. However, before this technology is ready for series production, a number of challenges have to be met, such as sustaining durability, ensuring the water supply under different operating conditions, and functionality of the system under all different climatic conditions.

The trend for reducing fuel consumption in customer-relevant driving cycles is the challenge for engine development in the future. Technologies that enable the intake temperature to be reduced have particularly significant potential here. Besides a reduction of the fuel enrichment required, the engine efficiency is increasing. ■

It's All in the Mix

_____ Will the engine—in particular the combustion engine—continue to be the heart of every vehicle in the future as well? To find out how a passionate engine developer answers this question and to get some insight into the challenges, trends, and technologies that will be important going forward, we spoke with Klaus Fuoss, head of engine development at Porsche Engineering.

Interview by Frederic Damköhler, Nadine Guhl   Photo by Jörg Eberl



Porsche Engineering *Mr. Fuoss, with all the talk about electromobility these days, how do you view the future of the combustion engine?*

Fuoss The combustion engine is alive and well. It will remain the primary source of propulsion in our cars for a long time to come. But biofuels and natural gas will play a growing role as an additional source of power. Over the long term, I believe a healthy mix of current fuels, biofuels, and natural gas will become the standard, though the actual development and ultimate success of biofuels will depend heavily on creating a favorable political climate. With regard to fuel consumption development of current vehicles, considerable potential for improvements can still be exploited through hybridization, downsizing, and energy management. Lightweight construction and reduced friction—particularly with regard to engines—are also increasingly the focus of attention.

What are the greatest challenges in engine development?

Fuoss Among the greatest challenges are the reduction of PM (particulate matter) and CO_2 emissions. Both are subject to binding legislation—and the standards are high. Lightweight construction is no longer just an issue in body development; engine development is increasingly affected as well. There are weight targets for engines, so even during the design phase we have to think about multiple integration of functions and components as well as what materials are used. While downsizing always creates opportunities, at the same time it requires attention to counteracting the associated higher stress on components. To address this, efforts are underway to master higher injection pressures in both gasoline and diesel engines. Moreover, in the future it will be increasingly important to find cost-effective solutions for worldwide use of engines in general. Here we face the challenge of developing concepts in such a way that they are compliant in different markets. The question is when a global solution makes sense and when it makes sense to differentiate according to local demands.

How is engine development at Porsche Engineering proceeding in order to be ready to address these future challenges?

Fuoss We maintain a constant focus on expanding our expertise in the relevant fields such as the simulation of gas exchange and mixture formation. We are also expanding our knowledge and methods with regard to lightweight construction. As an engineering service provider within the Porsche Group, we also profit immensely from our involvement in series development projects. We thus look at every single development step from an OEM perspective and we are accustomed to thinking that one step further; that is, to look at the vehicle as a whole. As a rule, that's exactly what our customers appreciate.

How far can you go with downsizing? Is the end of the road in view?

Fuoss In the next stage, the mass market will be dominated by 1.0- to 1.5-liter engines putting out the same power as today's 1.5- to 2.0-liter engines. Further downsizing only makes sense with reduced vehicle masses. There will also be a reduction in the number of cylinders, as it is not possible to endlessly reduce the individual cylinder displacement volume—I think we'll see two- and three-cylinder engines on the mass market. But here it is crucial to ensure that this does not cause negative impact in terms of comfort.

What is the outlook with regard to power? Is there a limit?

Fuoss The limits are ultimately defined by the customer. There will presumably always be demand for very powerful cars. Looking at the mass market—let's say 75 to 110 hp—this level of power will remain relatively constant. The objective here has to be reduced fuel consumption with the same level of performance, especially with regard to CO_2 targets.

What kind of engine would you someday like to develop?

Fuoss That's a tough question, since I have had the opportunity to work on nearly every common type of engine and number of cylinders, but a high-revving V12 could be interesting. But I can just as easily imagine working on a "best in class" high-efficiency engine.

How will we get around in 30 years?

Fuoss In 30 years we will predominantly be driving around in hybrid vehicles with engines that have been successfully downsized. We are also the generation that will get electric vehicles going in a big way and learn to really work with this new technology so that generations to come will no longer have any inhibitions in this regard. So in the future there will be a mix of fuel cell- and battery-powered vehicles, plug-in hybrids, hybrids as well as vehicles with combustion engines. But these vehicles will increasingly draw their power from CO_2-neutral electricity and CO_2-neutral fuels and thus be truly sustainable.

If you hadn't become an engine developer, what would you have done instead?

Fuoss That's hard to imagine. I probably would have become a person who always wanted to be an engine development engineer. ■

Klaus Fuoss

As the son of a self-employed auto mechanic, his passion for cars and engines was stoked in his childhood. After his studies at Stuttgart University, the engineering graduate spent several years working in the advanced engine development department at Audi AG in Neckarsulm, Germany, before joining Porsche in 1996. As an engine design specialist, he worked on several engine projects for Porsche AG and was also involved in the "Harley-Davidson V-Rod" project. In 2003, Klaus Fuoss moved to the U.S. and spent over four years with Mercury Marine, where he headed up the engine design division (outboard motors). Once back in Germany, in October 2007 Klaus Fuoss took over as head of engine development at Porsche Engineering.

Dimensional Management in Vehicle Development

A preventive quality assurance method

By Bernhard Mölzer, Michael Strobelt

____ In vehicle development, dimensional management is used as a preventive quality assurance method to ensure fulfillment of visual and functional requirements. This makes it possible to avoid potential problems before they occur. The overriding objective of dimensional management is to achieve high product quality without rework.

At Porsche Engineering, the dimensional management method is assigned to the Production Engineering department, which deals with process issues for vehicle and industrial projects on a cross-project basis.

Why dimensional management?

The ever more demanding requirements on products in terms of design, appearance, and function led to the development of dimensional management, a preventive quality assurance method that ensures the functionality and producibility of designs at an early stage. Dimensional management makes it possible to avoid potential problems before they occur. It enables engineers to fulfill required quality characteristics (joint scheme) and safeguard points of constriction and critical functions.

The three central components

Dimensional management is primarily comprised of three central components: "specifications—functional dimensions and joint scheme," the "reference point system," and "statistical tolerance analysis." In detail:

Specifications—functional dimensions and joint scheme

Components and modules are to be dimensioned in consultation according to overarching quality and functional characteristics. The values thus determined are called functional dimensions. The relevant characteristics for the product are summarized in a requirement catalog—for instance in a joint diagram or functional dimensions catalog. This is used in production for statistical process control (SPC) and error analysis.

Functional dimensions for individual parts or assemblies are documented in the respective drawings. In defining the functional dimensions, the dimensional management principle of *"As precise as necessary, as imprecise as possible"* should be observed. The proper balance between restriction and room for maneuver is necessary to produce a flawless product at an acceptable cost. It is also important to ensure the testability of functional dimensions, as what is technically feasible in practice often places limits on the theoretical ideal.

If, for example, a curved surface or a hard-to-reach edge is involved, it may be difficult or even impossible to measure the functional dimension reproducibly in reality. The result is high scrap rates, which in turn leads to a search for the error, intervention in ongoing processes, and other measures that—particularly in manufacturing—cause high costs. This can be avoided through intelligent definition of functional dimensions.

Reference point system (RPS)

The comprehensive reference point system (RPS) for the individual parts and assemblies up to completion of the product is the foundation for dimensional management. It is the basis for creating tolerance concepts and measurement planning as well as for the assembly concept.

The task of RPS is the precise positioning of a component/assembly in free space and the limitation of the six degrees of freedom (three translational and rotary directions of motion each) using the 3-2-1 rule. This applies to all fixed systems. For kinematic systems, the degree of freedom for the component that causes a motion must remain unrestricted. The RPS points should be in stable areas and ideally parallel to the component coordinate system in their alignment. An adroitly positioned RPS can enable tolerance effects in places that are neither of a functional nor customer-specific character.

Statistical tolerance analysis

Statistical tolerance analysis makes it possible to determine the influence of particular characteristics such as geometric dimensioning and tolerancing or assembly factors in the overall context. By analyzing this calculated data in combination with the required quality characteristics, it is possible to determine first pass yields and scrap rates. 1D tolerance calculation or 3D tolerance simulation is used for this.

The statistical calculation of quality and functional characteristics primarily shows whether the target parameters will be achieved with the present assembly concepts and the available quality of components or whether optimizations will be required to reach the targets. The task then is to develop solutions with the relevant departments.

Advantages

This analytical approach makes it possible to secure the required quality characteristics (e.g. joints and transitions) and functional requirements for components (e.g. points ›

There are various approaches to influencing a result:

> **Optimization of the assembly concept, thus reduction of contributors**
> **Optimization of the mounting concepts for individual parts**
> **Construction changes**
> **Adjustment/restriction of individual tolerances (caution: rising production costs)**
> **Optimization of the production process and thus improvement of the quality capability indicators of individual contributors (process capability cp or process capability indicator cpk—caution: rising production costs)**
> **Expansion of quality specifications (tolerance specification)**
> **Styling adjustments (modify critical joint designs, etc.)**

of constriction and mountability). Weaknesses in the styling, design flaws, and process risks also become visible and can be remedied as necessary. This enables significant reductions in the times and costs for development, production, and reworking.

Interface in the product creation process

Successful dimensional management spans the entire development process and requires continuous and close consultation with all involved departments (development, production, ›

1D tolerance calculation

- Mathematical calculation of tolerances using statistics
- From simple calculation (Root Sum Square method) to complex calculation using convolution of different distributions
- The latter in special tolerance calculation programs
- Suitable for preliminary concept calculations and simple relationships
- Also applicable with larger or more complex scopes

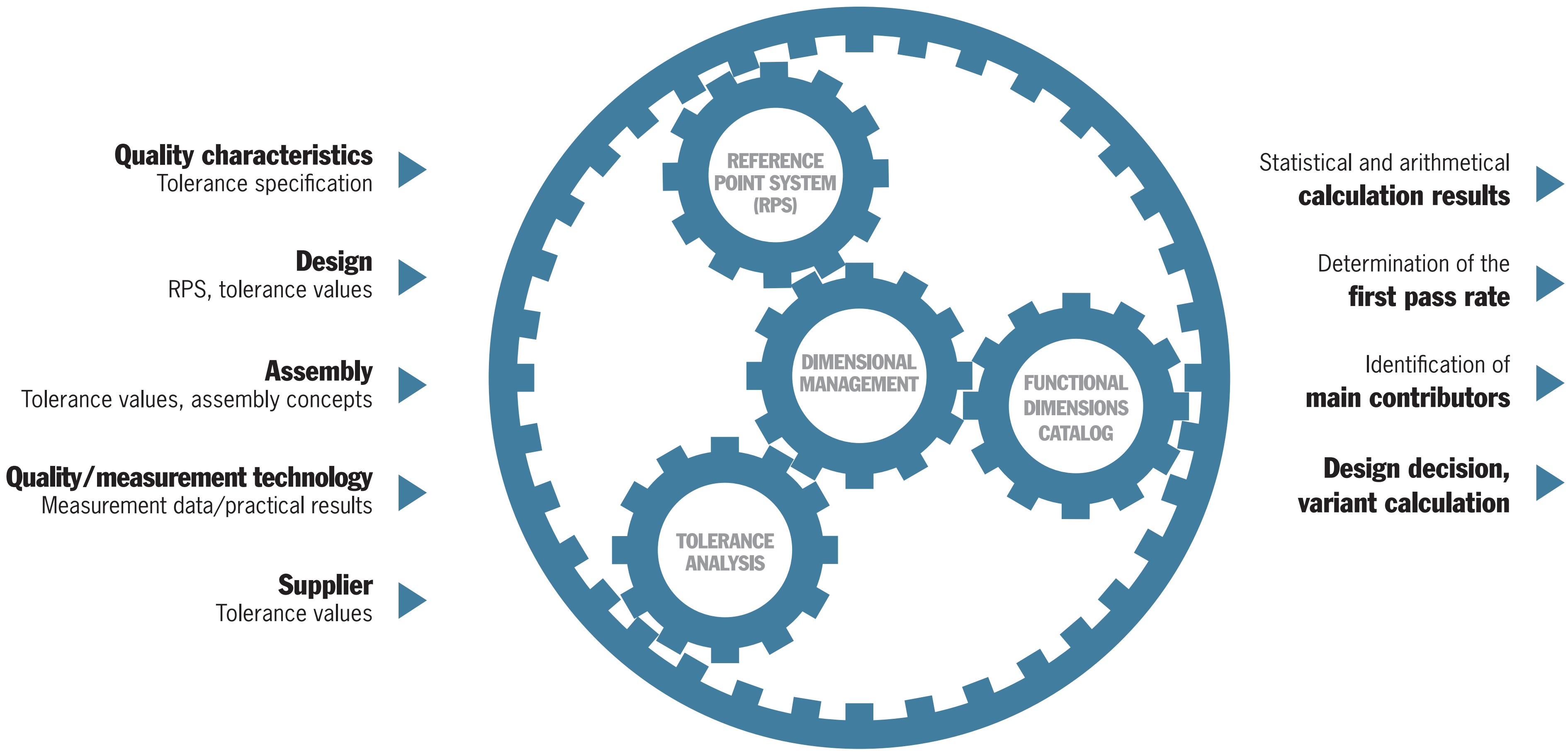
3D tolerance simulation

- Results from three-dimensional simulations of assemblies with randomly varying tolerances
- Result of over thousands of simulated production runs with statistical evaluation
- Suitable for large, complex contexts with a strong three-dimensional impact
- Advantages:
  – Summarization of multiple measurements in one simulation
  – Accounts for three-dimensional geometry and effects
  – Simpler variant evaluation
  – Evaluation of kinematic systems
  – Evaluation of flexible, overdetermined components
- Disadvantages:
  – Potentially complex setup
  – Higher software costs

Dimensional management – procedure in vehicle development

1	Definition of the scopes/quality characteristics (joint diagram, function dimension catalog)
2	Identification of relationships and contributors (assembly sequence, RPS design, tolerance concept)
3	Identification of factors and production process parameters (component, equipment, assembly tolerances and their distributions)
4	Execution of tolerance analysis (1D tolerance calculation/3D tolerance simulation)
5	Evaluation of results (Monte Carlo simulation) and estimation of contributors (Pareto analysis), determination of first pass yields (rework) with regard to required quality and joint specifications (from joint diagram/functional dimension catalog)
6	Documentation of tolerance analysis (including graphic representation)
7	Communication of analysis results to development teams
8	Definition of measures and development of concept alternatives in the development teams in case of “not-OK” results
9	Feed measured values into tolerance analysis and update

The dimensional management system



Every joint is in the right place—design and function in perfect harmony.

quality, and suppliers). This involves gathering required information, implementing it in dimensional management, and communicating the results back to the interfaces.

Dimensional management interfaces

> Design
> Development
> Assembly planning
> Quality of purchased parts
> Suppliers
> Production
> Measurement technology

To ensure the greatest possible positive impact of dimensional management, it must be brought into the development process at an early stage. Employees with dimensional management experience should ideally be involved from the concept phase onwards and provide consulting support with regard to RPS and assembly concepts. In the run-up to production, i. e. when initial measurement data already exists, the data can be fed back into the tolerance analysis to validate assumptions.

And its usefulness is not limited to the scopes of OEM-internal production. Suppliers of individual parts and assemblies can also benefit from utilizing the full spectrum of dimensional management.

Expanding and communicating knowledge

To prepare the next generation for dimensional management, guest lectures and papers are presented at the University of Stuttgart and the Karlsruhe Institute for Technology (KIT). Academic papers on the subject of dimensional management at Porsche Engineering have also led to collaborations with the Institute for Product Development (IPEK) and the Institute for Production Technology (wbk) at KIT. In addition to promoting education, Porsche Engineering also ensures that it is able to maintain and continuously raise its already high standard with regard to dimensional management.

Conclusion

Fulfillment of required visual and functional quality characteristics while reducing rework and process costs is the engine for the early application of dimensional management as a preventive quality assurance method in the product creation process. Thanks to the introduction of 3D tolerance simulation, it will be possible to handle complex problems more efficiently and in greater detail in the future. ■

911 (TYPE 991) Fuel consumption (combined):
12.4–8.2 l/100 km; CO_2 emissions: 289–194 g/km

Everyday **Extraordinary**

How Scania commercial vehicles and Porsche sports cars fit together

_____ The commercial vehicle manufacturer Scania and Porsche Engineering have been working together on truck development issues for more than ten years. Following several smaller projects, the two have been collaborating on the development of a new Scania truck cabin generation since 2010. At Scania, we met with Dr.-Ing. Harald Ludanek, Executive Vice President – Research and Development, Ms. Catharina Modahl Nilsson, Engineering Director – Cab Development, and Mr. Sven-Åke Edström, Senior Vice President – Truck, Cab and Bus Chassis Development.

Interview by Frederic Damköhler and Nadine Guhl   Photos by Dan Boman

Dr. Ludanek, at first glance it would appear that Scania commercial vehicles and Porsche sports cars are not a natural fit…

Dr. Ludanek: It's true that we are dealing with two products with completely different requirements. A Porsche sports car is prized by customers for its perfection and the excitement that it engenders, its power, its performance on the road, and its quality. A truck, by contrast, is a working machine that primarily distinguishes itself through reliability, durability, uptime, and practicality. While a passenger car meets customer expectations with an average service life of 5,000 hours of operation and a total mileage of around 150,000 km, a truck must be designed to achieve ten times this in both categories.

From your perspective, why does working together with Porsche Engineering make sense?

Dr. Ludanek: The design principles, physical principles, and many requirements of the body structures are the same. In working together with the engineers at Porsche Engineering, we can profit in particular from their experience in design and manufacturing processes. After all, lightweight construction and fuel consumption reduction play a major role for commercial vehicles as well. And the transfer goes in both directions: for example, in recent years high-strength materials and hot-stamped structural components such as those used in trucks have been increasingly used in car bodies to save weight and reduce fuel consumption.

Mr. Edström, how did the cooperation for the development of the next cabin generation come about?

Edström: Scania and Porsche Engineering had already been successfully cooperating in the field of truck development for several years before this project. It was important for Scania to find a partner with expertise in multiple areas, such as body-in-white structures, new methods in simulations and production planning, as well as a strong connection to prototype workshops. It is quite natural that the time frame for the development process in the commercial vehicle industry is much longer than in the passenger car industry. We expect to benefit from new methods from the automotive industry and achieve quicker turnaround and better results. ›

Every successful business relationship thrives on a lively exchange based on mutual trust: the cooperation of Scania and Porsche Engineering is no exception.

In your experience, what distinguishes Porsche Engineering from other engineering service providers?

Dr. Ludanek: Porsche Engineering has the advantage of being directly connected to the automobile manufacturer Porsche. Their explicit awareness of customer requirements and understanding of the peripheral issues that play a role in completing the job economically are hugely beneficial in our project work. In particular, their differentiated view from the various car development perspectives and transferring this experience to truck development projects often results in completely new solution approaches. The experience and knowledge gained through procedures and methods that have become standard practice in the car sector combined with the specific requirements of the commercial vehicle sector generate new ideas and solutions that benefit our customers.

Ms. Modahl Nilsson, what is so special about a Scania truck compared to those of competitors?

Modahl Nilsson: Scania is very customer-oriented. The main focus is on operating performance in line with profitability. Low fuel consumption, optimal uptime, and low service costs are decisive factors for logistics companies. The truck driver should be able to easily operate the truck without being stressed or overtaxed in the process. In terms of the person-to-machine interface, the driver receives excellent feedback on driving performance.

What overall challenges will the commercial vehicle industry face in the future?

Edström: Future developments in the commercial vehicles sector will no longer be characterized by a *single* improvement. The aim is to substantially improve efficiency in the field of logistics through a range of enhancements. Just as in the automotive industry, commercial vehicles are faced with the challenges of lightweight construction, energy efficiency, reduction of fuel consumption and emissions, and the use of trucks with alternative fuels as well as more stringent passive and active safety requirements. Moreover, this additional technical equipment will only find acceptance if it is economically viable. In the future, linking vehicles in the logistics network will create enormous potential for advancement in this area.

Considering these challenges, where do you see further potential for collaboration with engineering service providers?

Edström: A variety of collaborative models are possible. Beyond the traditional issues of cabin and component design, there is also a push to improve existing work methods; here, the expertise of development service providers can definitely be very useful.

Dr. Ludanek: In the future, we will be forced to accept shorter service lifetimes for electrical and electronic developments, as the trends and methods in this area are changing in ever faster cycles. Driver assistance systems, which are increasingly prevalent in the car sector, will soon be introduced in the commercial vehicle sector as well—here again, we can benefit from others' experience. A lot of the advanced technologies will first reach the customer through the car sector. That also goes for advanced materials.

How about the other way around? In your opinion, is there potential for the automotive industry to learn from the commercial vehicle industry?

Dr. Ludanek: Collaborative projects should always generate synergies for both parties. Truck development focuses on fuel consumption and operating costs. Many development ›

Porsche Engineering regularly puts its knowledge to use for other industries and projects in different technical fields. Scania relies on Porsche expertise and both sides profit from a fruitful exchange of ideas.

Dr.-Ing. Harald Ludanek

Executive Vice President, Head of Research and Development

Dr.-Ing. Harald Ludanek joined Scania in 2012. After graduation, he joined Volkswagen AG, where he held various positions. He also worked at Škoda Auto MIBol/CZ. Before joining Scania, Harald Ludanek was Head of Vehicle Development at Volkswagen AG. At Scania, he was appointed Executive Vice President and Head of Research and Development.

Catharina Modahl Nilsson

Engineering Director for Cab Development

Catharina Modahl Nilsson joined Scania as a trainee and has held numerous positions within the company, mainly in research and development but also in marketing. Since 2012, she has held the position of Engineering Director for Cab Development at Scania.

Sven-Åke Edström

Senior Vice President Truck, Cab and Bus Chassis Development

Sven-Åke Edström, who joined Scania as a trainee, began his career with the company as a design engineer in the Industrial and Marine Engines Division, focusing on diesel engine design. Since then, he has held various positions at Scania, both in Sweden and abroad. In 2009 Sven-Åke Edström was appointed Senior Vice President for Truck, Cab and Bus Chassis Development.

concepts can be economically implemented in this area thanks to the very long service lives and high mileage. Individual measures frequently have to prove their usefulness in an integral interaction with regard to reliability, serviceability, and operational safety. Against the backdrop of CO_2 reductions and fleet operations, this holistic perspective can benefit the car sector as well.

Edström: The truck sector is also leading the technology development in terms of robust, durable technology.

How will e-mobility affect the commercial vehicle industry?

Modahl Nilsson: We have to take a differentiated look at the application cases. In local urban distribution and commuter traffic, hybrid drive systems will be phased in. Especially in stop/start scenarios, a hybridization of the drivetrain will enable recuperation of braking energy and acceleration support. In contrast to cars, purely electric driving in trucks will remain the exception and will only be feasible on certain types of routes. In long-distance road haulage, purely electric, autonomous driving will struggle to gain acceptance due to the low storage density of the batteries. In Sweden, however, concepts for the electrification of major transportation routes to counteract the current deficiencies of battery technology are being considered.

What role does design play for Scania trucks?

Edström: At Scania, truck styling is important—and it secures the Scania brand identity. Scania has a strong exterior styling that resembles a helmet, highlighting essential characteristics of Scania trucks such as safety, uptime, robustness, and quality. Its importance is clear when one considers that the styling of the interior must balance functionality with a living space for the driver. Of course, styling is not the main criterion, but it is essential to foster drivers' sense of identification with the brand, which induces better, more careful use of the truck—which in turn results in lower operating costs.

What will trucks look like in 20 years?

Dr. Ludanek: 20 years from now, trucks will have technical improvements for low fuel consumption, e.g. low drag coefficients, optimized aerodynamics, and easy access. In terms of functionality, the truck will be more closely connected to the logistics process. Driver assistance systems will ensure easier handling and operation. Service and maintenance will be monitored and detected by the operating system itself. The truck driver will have an office and a comfortable living space in one place.

If you could be a developer at Porsche for one day, what would you like to develop?

Dr. Ludanek: Porsche is a fascinating sports car company with emotional products. In the Porsche Cayenne, the Porsche engineers brilliantly succeeded in combining sporty characteristics with robustness and off-road-performance. Whenever you drive a Porsche Cayenne in rough off-road conditions, you are inevitably captivated by its performance. So I would love to develop the next generation of the Porsche Cayenne.

Edström: A Porsche Carrera's road stability and handling are very impressive as well. Why not participate in that development area to learn more about the secret to achieving that?

Modahl Nilsson: I'm impressed by the strong Porsche brand, the emotions, and the heritage connected to Porsche's identity. This seems to be deeply rooted not only in your customers' minds but also in the pride shown by every Porsche employee. As an engineer I would appreciate being part of the backbone of the Porsche lineup—and developing the next generation of the 911. ■

www.scania.com/trucks/

THE COOPERATION BETWEEN SCANIA AND PORSCHE ENGINEERING

Ever since the Swedish commercial vehicle manufacturer Scania and Porsche Engineering began working together to develop a new truck cabin generation in 2010, the focus always extended beyond typical Scania styling and first-rate functionality to include a continual effort to optimize the design of development and production processes. "Only when our developments smoothly plug into the Scania development process, can be efficiently produced, and create added value for Scania have we done our job successfully," says Malte Radmann, CEO of Porsche Engineering. "This is the standard that our engineers have been following with customers ever since Ferdinand Porsche founded his engineering firm over 80 years ago."

Porsche engineering services have always involved transferring experience and expertise from the automotive industry to related sectors. "We always put ourselves in the customer's position and try to combine an awareness of the industry-specific requirements, such as competing product and manufacturing cost pressures, with our special expertise from the sports car development process," says Helmut Fluhrer, head of the Scania cabin development project at Porsche Engineering. "To date, we have always succeeded in creating critical synergies for both sides in spite of all the challenges. That's what makes our project so exciting."

911 (TYPE 991) Fuel consumption (combined): 12.4–8.2 l/100 km; CO_2 emissions: 289–194 g/km

CAYENNE Fuel consumption (combined): 11.5–7.2 l/100 km; CO_2 emissions: 270–189 g/km

CAYMAN Fuel consumption (combined):
8.8–7.7 l/100 km; CO_2 emissions: 206–180 g/km

911 (TYPE 991) Fuel consumption (combined):
12.4–8.2 l/100 km; CO_2 emissions: 289–194 g/km

BOXSTER (TYPE 981): Fuel consumption (combined):
8.8–7.7 l/100 km; CO_2 emissions: 206–180 g/km

_____ Its affinity for curves is unsurpassed among sports cars. With a longer wheelbase, a completely new chassis, and less weight, the new Porsche Cayman sets a new standard for driving dynamics in its class. The completely redeveloped two-seater is the third Porsche sports car model series after the 911 Carrera and the Boxster to feature an innovative lightweight body design.

Third-Generation Master of Curves

The new Porsche Cayman

The new Cayman is more striking than ever. Its proportions are new, and yet it is clearly a Porsche sport coupé.

Design: more distinctive than ever

The extended wheelbase with shorter overhangs and 18- and 19-inch diameter wheels with larger rolling circumference are distinctive visual cues of the car's enhanced driving performance. Its design is characterized by precise lines and precisely modeled edges. Typical of the new design is the shoulder line, which flows out of the starkly arching wing into the rear side section. Particularly striking is the dynamic indentation in the door, which directs the intake air to the distinctive inlet in the rear side section. This offers the most prominent visualization of the concept of a mid-engine car.

From the front end, the new Cayman is marked by its dominant cooling air inlets. They house the round front lights with four-point daytime driving/position lights—an unmistakable hallmark of the new Cayman. Just as unique to the new generation of the sport coupé are the large, low rear lid made of aluminum and the rear section with its wrap-around edges. The overall appearance of the Cayman is more independent than before, and it is well differentiated from the previous model.

Engine: six-cylinder with high engine speed concept

Porsche has outfitted the Cayman with unequivocal sports engines that combine massive torque with powerful performance at high engine speeds. This high engine speed concept makes it possible, among other things, to reduce the displacement of its basic power train by 0.2 liters over its predecessor while adding power. With specific power of 74.8 kW/l (101.6 hp/l), the 2.7-liter engine is the first Cayman engine to cross the magic threshold for sports car engines of 100 hp per liter. The new engines suck air in through the left and right air intakes. ›

Intelligent efficiency: on-board electrical system recuperation, thermal management, coasting

With their economical power, the flat-six engines positioned in front of the rear axle make the Porsche two-seater the epitome of efficient performance. With direct fuel injection, thermal management, on-board electrical system recuperation, and the auto start/stop function, the drives of the two currently available models are up to 15 percent more economical.

In conjunction with the PDK transmission, the Boxster, the 911 Carrera, and now the new Cayman share the principle of coasting: only calling up engine power when it is actually required. When the car is coasting and the engine is disengaged, fuel consumption is minimal. In practice, this amounts to potential fuel savings of up to a liter over 100 kilometers.

Extraordinary driving dynamics: agile in curves

The driving dynamics of the Porsche Cayman are extraordinary. Even more than before, the interaction between the mid-engine design and the running-gear setup secure it the top spot in its class. The basic geometry provides the ideal prerequisites: a 60-millimeter longer wheelbase ensures greater stability at top speeds, the wider track on both axles generates greater driving stability and agility in corners, and wider-diameter tires provide better traction up to the limit. The Porsche engineers placed great importance on fine-tuning the Cayman not only for driving dynamics and agility, but also improved comfort and day-to-day usability.

Highly responsive and efficient: electromechanical steering, better braking

The electromechanical power steering replaces the hydraulic system previously used in the Cayman. Its capability enables the driver to experience the Cayman's agility even more intensely. Along with the improved driving performance, the Cayman's brake system is now more powerful as well. In addition to being equipped with stiffer brake calipers on the front axle, an optimized guideway, and larger brake surface, the brake disc cooling was also improved.

44 %

Proportion of aluminum in the new Cayman body-in-white

The body: lighter, stiffer, sportier

The body of the new Cayman is a complete redesign based on the bodyshell of the Boxster. What that means: thanks to the innovative aluminum-steel composite lightweight construction, the weight of the bodyshell was reduced by around 47 kilograms. At the same time, the static torsional rigidity was increased by 40 percent. In other words: the Cayman drives more precisely than ever before. In its new lightweight bodies, Porsche uses steel only where necessary. Instead, die-cast aluminum, aluminum plate, magnesium, and high-strength steel are used, custom-fit for the particular use in the body to minimize the material used while ensuring maximum stiffness values. Roughly 44 percent of the new Cayman body-in-white is comprised of aluminum, including the front end, floor and rear end, doors, and both hoods. The lift on both axles has been reduced compared to the previous model, which translates into greater stability at high speeds. The wing is optimally integrated in the rear end and extends in an arc automatically or manually. With its 40-percent larger effective area, it generates more downforce than its predecessor's rear spoiler while creating less drag.

Better performance, better safety, more fun—the new Cayman more than lives up to its sterling reputation. Quite simply a master of curves. ■

www.porsche.com/cayman

Especially characteristic are the dynamic recesses in the doors, which guide induction air into the distinctive air scoops on the rear side panels and then directly to the engine.

Also distinctive: the large, low tailgate made of aluminum and the rear section with its wrap-around edges.

Passion for Safety and Aesthetics

_____ The interior is equally important to the overall impression created by the new Cayman. The interior's design focuses not only on appearance and styling, but also on functional development requirements according to FMVSS 201u.

By Thorsten Beck   Photo by Jörg Eberl

Ensuring passive vehicle safety in the "greenhouse area" plays an important role when designing the vehicle interior.

Strategic orientation

As part of the functional development of the vehicle interior, the U.S. law FMVSS 201u plays a central role. This law is an important factor in ensuring passive vehicle safety and focuses in particular on head impact protection in the “greenhouse area”—the area above the top of the door panel that is delimited by the windows, the vehicle roof, and generally the A-, B-, and C-pillars.

Development process for the Cayman

The project work began as soon as the first package concepts were initiated. Early inclusion in the vehicle development process beginning in the concept phase proved highly beneficial. This made it possible to coordinate directly and efficiently in the intricate development process with the various interface partners such as vehicle safety, interior, package, and styling. For example, deliberations regarding the design were aided by design sketches that already included provisions for deformation to enable compliance with FMVSS 201u requirements as well as other package requirements.

Definition of the areas of deformation was coordinated closely with vehicle safety. The objective was to achieve the optimal combination of cost-effectiveness, styling, variant diversity, and lightweight design while fulfilling safety requirements. Deformation elements were designed to comply with FMVSS 201u while considering other aspects such as cost and weight. Free Motion Headform (FMH) calculations were utilized in order to optimize the functional behavior. To conduct the development process without pre-prototypes, the high number of FMH test constellations makes use of the finite element method (FEM) indispensable.

The initial FMH calculation model was based upon the virtual pre-prototype. The FEM calculation was necessary in order to further develop and confirm the deformation concept prior to design-release. Continuous coordination between FEM calculations and component layout helped to ensure an optimal design for the greenhouse area, with little need for additional design changes.

Comparison of test results with the calculations revealed no major deviations—proof of the quality of the function-based design and the calculation model.

Test results from the prototype phase are one of the primary bases for series development. Based on results from crash tests, head impact tests, system tests (such as alternating climate tests) of the complete vehicle, and individual component tests, adjustments continue to be made before settling on the final styling. One particular challenge proved to be the integration of the sun visor, which was only made possible by an innovative deformation concept. Cross-departmental cooperation was exceptionally efficient in this regard.

Optimization through automatic processes

Beyond the success of the project itself, it also resulted in optimizations of development processes that have already benefited subsequent projects. Efficiency was improved through an end-to-end FEM calculation process that includes every step from model construction through analysis. An automated evaluation tool reduces analysis time and improves comparability.

An automated tool for determining the test points and test ranges, stipulated by FMVSS 201u, was developed as well. Immediate creation in the CAD environment saved intermediate steps that had previously been necessary and improved the documentation process, which also resulted in significant time savings. ■

Quicker Results with

Rapid Control Prototyping

____ Rapid control prototyping (RCP) is a method for flexible and efficient functional design during the model-based software development process. Porsche Engineering uses this technology to make it possible to "experience" future engine control functions at an early stage in the development process.

By Heiko Junker

As the complexity of engine control functions grows, so does the software development time required. This ongoing trend is partly due to legal requirements (such as emissions controls) becoming more stringent. This requires the continuous development of new complex functions that span different systems. The hybridization and individualization of functions for optimizing the drive chain characteristics of the respective vehicle also pose new challenges for function developers. This means that it must be possible to develop functions independently of the Electronic Control Unit (ECU) supplier to be able to reduce development cycles and therefore costs.

Software development often too rigid

In software development and the application of ECU software, the most common approach is that both the ECU hardware and software are provided by the same supplier. If new functions, function enhancements or error rectifications are required, the person responsible for the function or the application engineer creates a corresponding request. The desired changes are integrated by the supplier of the ECU or software and made available in the next software release. The product specifications, which are frequently written in prose, result again and again in differences between the requested function and the one implemented. In particular with complex software requirements, this results in frequent recursions that can be avoided by using RCP.

Rapid control prototyping (RCP) for easier work

The various ECUs in vehicles have very different control and regulation functions. Sensors detect the current condition of the control process and forward the information to the ECU so it can calculate variables. The ECU can then influence the controlled system with actuators and set the desired condition (see illustration on the right).

In conventional prototyping, when the complete regulation or control model is created, it is tested using special prototyping hardware. Rapid control prototyping makes it possible to create new function components with little effort and to expand existing program structures or even replace them. Immediately afterwards, the function can then be validated on a bypass platform. This bypass platform can be a special test system (target) or even the future production control device (ECU). RCP thereby provides an end-to-end process—from the function design right up to program execution on a regulation and control system. This makes it possible to test important functions quickly and under real conditions, for example in the vehicle, and to get early feedback on the cost and feasibility of new functions. Problems are detected early and can be rectified with considerably less effort. It is important to distinguish between internal and external rapid control prototyping.

Internal rapid control prototyping (on-target prototyping)

Internal rapid control prototyping does not require additional hardware and is therefore an inexpensive solution that uses the ECU used in production development. The ECU supplier has to prepare the ECU software accordingly for the integration of bypass applications. For this purpose, the ETAS EHOOKS-PREP program, which is a component part of the ETAS EHOOKS tool chain, can be used. The program encrypts the additionally required address information and free memory space for the later integration of bypass hooks and new function code. The bypass hooks in the control device ›

Internal rapid control prototyping

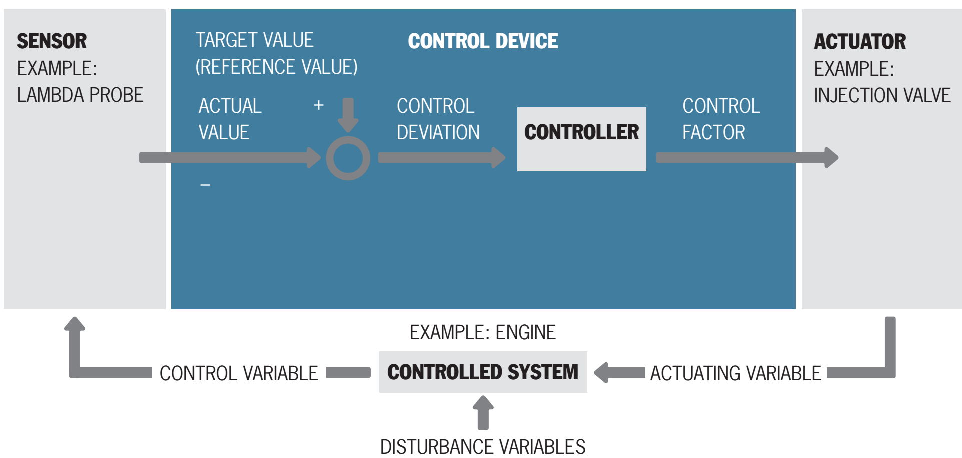
ADVANTAGES:

> No additional hardware required (several development vehicles can be flashed with a single RCP software release)
> Original control device timing

DISADVANTAGES :

> Processing time for a new software release (time for the build process + flashing to control device)
> Restricted computing power
> Limited program and application memory
> Restricted I/O

Control circuit signal flow chart

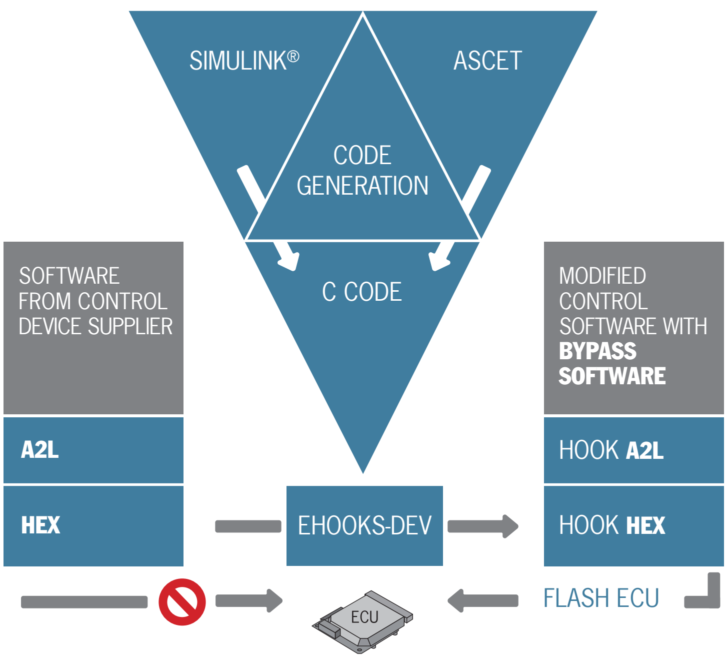


software required for a bypass application can then be inserted independently of the supplier of the ECU or software.

The illustration below shows the necessary steps for integrating additional functions. The ECU software is usually provided as a *.HEX file (executable program code for the control device) and an *.A2L-description file (address-to-label: list of the memory addresses and respective symbolic names of the objects in the program code). This means that the ECU can be flashed as usual in series development.

Using tools established on the market such as Simulink® or ETAS ASCET that are used in model-based software development, it is possible to create the new function structures and therefore the C code. In the EHOOKS-DEV program, the user has to set up the inputs of existing functions that are to be overwritten—the so-called bypass hooks. Read access to all signals that occur in the existing program code is possible, allowing them to be used for processing in the new bypass function. In the subsequent build process, EHOOKS-DEV creates a new, executable program code containing the new bypass software for the production ECU. This can be flashed onto the ECU and executed. The special feature of a bypass application is that the bypass function can be activated and deactivated while the program is running. This gives the application engineer the option of comparing the function structures with the original program code online, for example.

Internal rapid control prototyping creation process



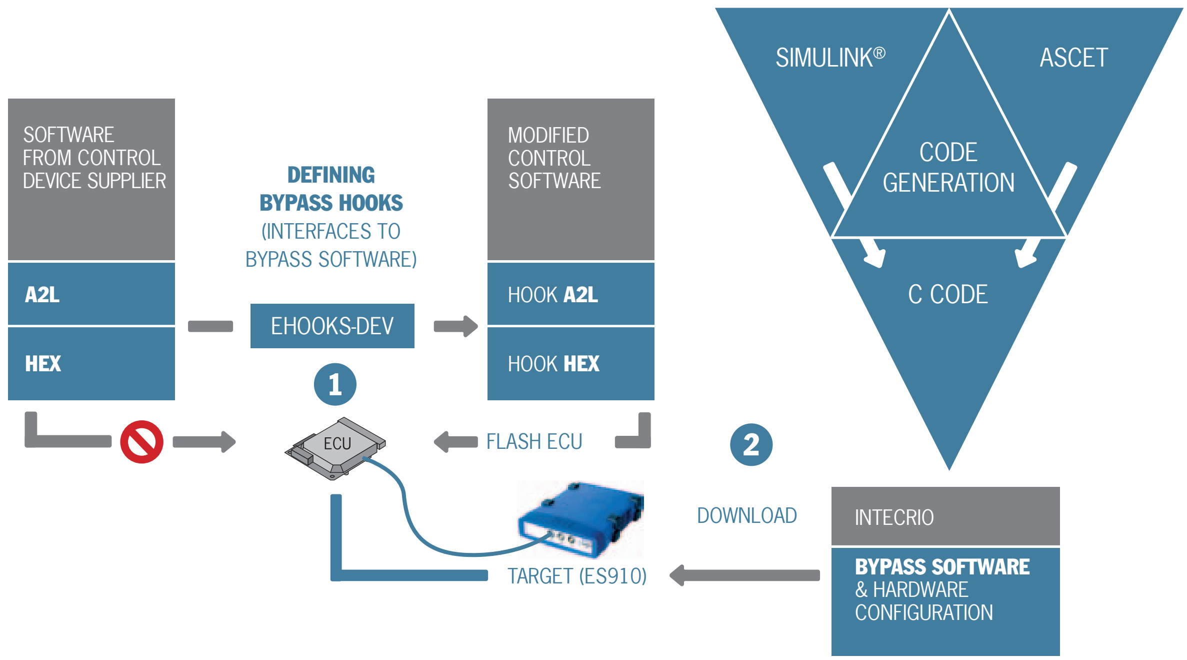
External rapid control prototyping

With very large internal bypass functions, a lack of memory space or overloading the existing computing power of the production ECU can mean it is necessary to switch to external rapid control prototyping. With this technology, it is also possible to integrate new sensors or actuators in the application. With external rapid control prototyping, the new bypass function is computed on separate hardware—the target. The target is connected to the series control device via a special, real-time capable ETL interface. Signals can be read and written back via this connection. The illustration on the right shows the necessary steps for using the powerful ETAS ES910 prototyping and interface module.

In the first step, just as with the internal method, the bypass hooks and the signals to be read must be set up with the EHOOKS-DEV application. This defines an interface to the future bypass software. The program code created with a build process with EHOOKS-DEV can be flashed onto the production ECU. This software solely contains a service for the ETL interface for exchanging data with the target. If the interface is to provide other data, the first step must be repeated.

The second step involves defining the hardware configuration, for example, of additional I/O components that could be connected to the ES910, and the interfaces for the bypass function. These settings are made using the ETAS INTECRIO application. In this case the C code from the Simulink® or ASCET models is also integrated. The INTECRIO application uses the information

External rapid control prototyping creation process



External rapid control prototyping

ADVANTAGES:

- High computing power
- More or less no resource restrictions
- Fast turnaround times (development cycle)
- Additional I/Os possible
- Safety aspect ("fall-back" to control device)

DISADVANTAGES:

- Additional hardware (target) required
- Possibly other timing response than on the original control device

and the bypass models to create executable program code for the target. This can be executed within a short time via a download or an Ethernet interface. If the target is to be operated independently of an operating computer, the program code can be additionally flashed to a non-volatile memory space. The compile times for creating an executable bypass on the target are significantly shorter.

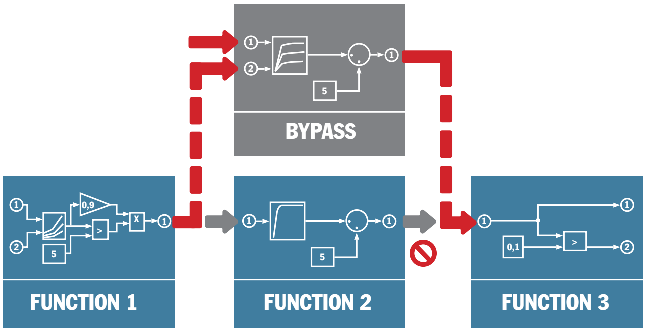
The fast lane—bypass applications

Existing input and output signals of the ECU functions are used in a bypass function to integrate newly developed or adapted functions. After calculation, the results of the new function are written to memory cells that read in existing follow-on functions. The bypass functions here can range from being simple constants to functions that replace the entire function apparatus in the control device.

The simplest form of a bypass is the variable bypass, also known as slewing. In this process, a memory cell of a value already present in the control device is described with a constant value of an externally calibrated value. The bypass for the calibrated value allows the variable value to be manipulated during the runtime of the ECU.

The most well-known of all bypass types is the function bypass (see illustration ›

Principle of the function bypass



at the top of the page). A new function is coupled with the existing functions of the ECU. Internal values are made available to the bypass function as inputs. The output values are written to the memory cells of the variable or function to be replaced. In an external bypass, additional electric inputs or outputs can be fed into the function via special I/O hardware.

In an application bypass, the driver layers of the inputs and outputs are made available by the ECU as interfaces to the application layer. The hardware, drivers and operating system of the ECU are used in this process. The original input and output signals of the ECU can also be used.

In a full bypass (conventional prototyping), the ECU is completely replaced by an experimental system. In this bypassing process, not only the application layer is replaced but also the drivers for sensors and actuators, the operating system and also the interfaces for the vehicle buses. Full bypass systems are mostly used in new developments in which either the ECU hardware or the software platform is not yet available.

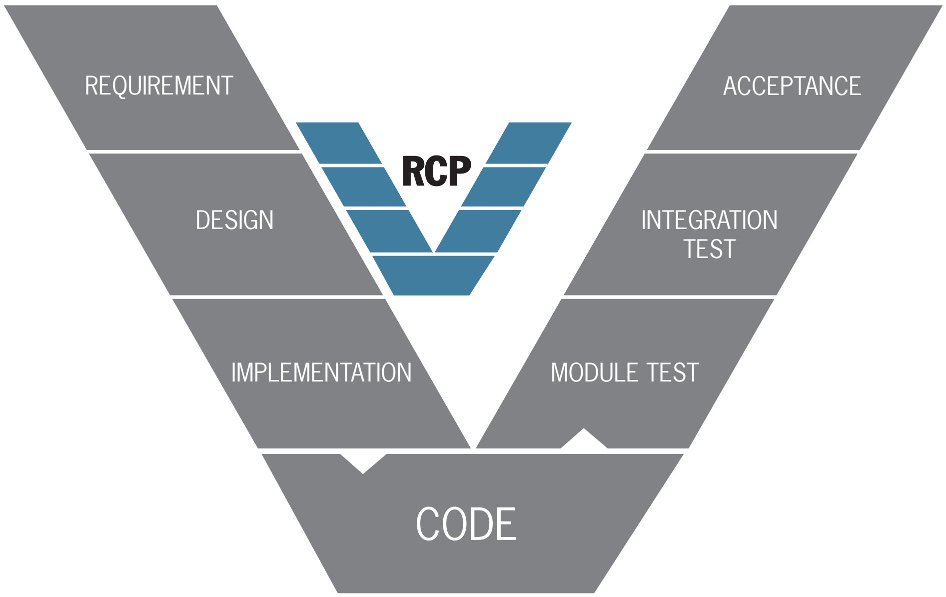
Spoilt for choice

External and internal rapid control prototyping complement each other in the world of model-based software development. The development engineer has the option of selecting the optimum system for each individual problem. However, as development progresses, the engineer can still switch between the two methods without great effort.

For complex function alterations, it is recommended to start with external rapid control prototyping. In this process, small function components can be changed quickly on the test bench or even in the vehicle. For example, 1D engine characteristics can be replaced

Using rapid control prototyping in the development process: a Porsche 918 Spyder prototype

Position of rapid control prototyping in the software development V model



with 2D engine characteristics and parameterized in just five minutes and the changed function can then be immediately executed as a download on the target. In addition, if new actuators and sensors are used, the target can be expanded with additional inputs and outputs to connect these and integrate them in new functions or function enhancements. Here it is also possible to connect additional bus interfaces such as LIN, CAN or FlexRay.

On the other hand, internal rapid control prototyping is particularly suitable for urgent function enhancements or for the quick correction of software errors that occur in development. This allows incorrect function structures to be replaced, for example an AND gate can be replaced with an OR gate. Then it is possible to distribute the new software to the test vehicles independently of the supplier of the ECU or software in order to continue testing without a major delay, for instance.

Development process

As part of the introduction of a Porsche standard RCP tool chain for the Porsche development process in the area of engine ECU software, the Porsche Engineering team evaluated commercially available systems. They decided on the ETAS EHOOKS tool chain due to the synergies with Porsche Engineering hardware and software already in use as well as the simplicity of the creation process. The first major use of this technology was in the 918 Spyder project. Using RCP, a great number of ideas can be applied in the development of innovative drive concepts, as was required in the 918 Spyder project. To safeguard such prototype software, Porsche Engineering uses hardware-in-the-loop technology. It is a fixed part of the V development process and prevents possible engine or vehicle damage during critical functions. RCP technology gives the Porsche development engineers new possibilities for efficiently solving problems in model-based software development. ■

Aerodynamics and Thermal Management

Interaction in the context of vehicle development

____ The constantly rising pressure on carmakers' development departments to reduce fuel consumption and exhaust emissions while maintaining current comfort and quality standards has led to intense development activity in the fields of aerodynamics and thermal management.

By Patrik Gisch

New wind tunnel in Weissach

In addition to simulation and calculation methods, test facilities such as wind tunnels, climatic wind tunnels, and test tracks remain important for development engineers in their work. As part of the ongoing expansion, a new wind tunnel—where engineers can test vehicles at wind speeds of up to 300 kilometers per hour—is being built at the Porsche Development Centre in Weissach. This state-of-the-art wind tunnel will meet future requirements for vehicle development, in which energy efficiency will play an increasingly important role. The new facility will help developers sharpen Porsche's already formidable expertise in the fields of aerodynamics and design.

Exceptional design combined with optimal aerodynamic efficiency have been classic Porsche hallmarks from the very beginning. As the wind tunnel will not be open solely for internal Porsche designs but also available for external customer projects, the facility has direct access to the adjacent design studio and separate entrances for discreet work on development projects.

A broad range of activities

One typical and widely known field of application for vehicle wind tunnels is optimization of the aerodynamic drag coefficient value (Cd value) of a vehicle as an important contribution to reducing consumption and improving performance. But aerodynamic drag coefficient is not the only focus in aerodynamics development. Engineers also concentrate on a range of other factors that at first glance may not be apparent as traditional aerodynamics issues. Other issues include improving a vehicle's driving stability through precisely balanced aerodynamic lift forces on the front and rear axles, directional stability, and crosswind behavior. These factors contribute to driving safety as well as enhancing performance, for example during use on the racetrack.

A Porsche 911 in the wind tunnel: a typical scene in the field of aerodynamics development

Aerodynamics and styling define the classic brand design

As aerodynamic development work necessarily also influences the shape of the vehicle, the aerodynamics and styling disciplines work together in a symbiotic relationship. For example, aerodynamics measures and components must have not only a technical function but also, by being visible or invisible, support the classic design language of the brand in the vehicle's design.

Aerodynamic measures on the vehicle's underbody and wheel well areas, or the reduction of flow through losses at radiators, represent the greatest potential for "design-neutral" aerodynamic optimization, thus allowing the vehicle stylists greater freedom in designing the outer shell.

More comfort through optimal aerodynamics

Beyond efficiency factors, performance objectives, and safety requirements, in modern vehicles comfort aspects are an increasingly important part of the quality equation and thus impact the decision to buy as well as customer satisfaction. Draft avoidance in convertibles or vehicles with mobile roofs, keeping side windows and exterior mirrors free of soiling, and reducing wind noise are examples of requirements that aerodynamics engineers have to examine closely and optimize from a comfort standpoint, because comfort is a top priority.

The most promising optimization approaches determined digitally (without test prototypes) in the early stages of a vehicle's development using calculation and simulation tools ›

Aerodynamic forces are analyzed in minute detail in the wind tunnel using state-of-the-art visualization and measurement technology.

are tested extensively in later stages of the development process in wind tunnels and optimized further to achieve objectives. Moreover, component forces caused by air flowing around and through the vehicle are analyzed and reduced as necessary in the wind tunnel. Using state-of-the-art visualization and measurement technology, the aerodynamic forces on doors, hoods, windows, sunroof, rear view mirror glass, and the expansion lids of convertible roofs can be measured, visualized, and modified.

The aerodynamics engineers from Porsche Engineering also regularly put their experience and methodology to use in developing or optimizing products from other industrial sectors: for example, designing a small wind power plant (wind turbine), working on trains, or paint shops.

Interaction of aerodynamics and thermal management

One of the core tasks for aerodynamics engineers is securing cooling and ventilation functions by providing for an adequate and homogeneous flow of cooling air. By achieving a flow-optimized overall cooling air path, the cooling air resistance—in other words, the proportion of the overall air resistance caused by cooling air flow—can be reduced to a minimum. Here, aerodynamics and thermal management interact directly.

In particular the efficient design and determination of the size and position of the cooling air intakes, the design of supply and exhaust air ducts, and not least the appropriate radiator through which the air flows deliver discernible contributions to reducing wind resistance. These components and systems are designed and optimized by aerodynamics engineers using 3D computational fluid dynamics (CFD) flow calculation simulation tools. Thus in addition to traditional engine cooling, aerodynamics can also be used to cool brakes, power units, fluids, and charge air.

Diverse thermal management solutions

At Porsche Engineering, the field of thermal management extends from traditional cooling system design for combustion engines to control of all heat flows in the vehicle, assisting the reduction of fuel consumption, thermal management of alternative drive concepts, and thermal interior comfort.

Beyond computer-aided heat management simulations in early stages of development for designing and dimensioning cooling systems, prototypes and pre-series vehicles are used to test and assure the cooling function, particularly in the Porsche climatic wind tunnel or appropriate test courses.

Efficient cooling air flow reduces the overall air resistance.

Precise routing of air around and through the vehicle for optimum aerodynamics and targeted cooling and ventilation

Thermal management on the test track

To test cooling functions, the 2.9 km course at the Porsche proving grounds in Weissach is set up like a racetrack with long straightaways, fast curves, inclines, and switchbacks. It is also very well suited for testing component and coolant temperatures under the influence of extreme acceleration phases (positive as well as negative acceleration).

With its 12.6 km circular high-speed track, the proving ground at the Nardò Technical Center in southern Italy, which Porsche Engineering took over in May 2012, offer the opportunity to determine component and fluid temperatures at high speeds and sustained top speeds. These conditions enable testing of the transmission oil cooling, among other factors. The track is approved for speeds of up to 330 km/h, and the outermost lane allows speeds of up to 240 km/h without centrifugal forces.

Direction: future

Future technologies present new challenges for thermal management. In particular, projects in the field of alternative drive concepts require exceptional development acumen with regard to thermal management. The task for thermal management specialists lies in developing new solution approaches for thermal management of hybrid components, electric drives, electrical components such as power electronics, and naturally traction batteries as well.

But it is not only the cooling function that demands new developments and innovations. The heating of components and the vehicle's interior in cold ambient temperatures must also be resolved efficiently. The exhaust heat previously provided for "free" by the combustion engine is not available in purely electrically driven vehicles and must be provided by other means. The efficiency of these measures has a direct impact on the range of the electrically driven vehicle. Using the thermodynamic test bench developed by Porsche Engineering (featured in Porsche Engineering Magazine 2/2012) in combination with a 300-kW source-sink high-voltage test bench, these development tasks are implemented for components, systems, and complete vehicles for customers worldwide.

Further expansion of the Porsche infrastructure as well as the many years and diversity of experience of the engineers in the field of aerodynamics and thermal management will enable Porsche Engineering to keep pace with rising customer expectations and legal requirements. ■

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