Issue 1/2012

Porsche Engineering Magazine

Shift into gear for the future.

911 (Type 991): fuel consumption (in l/100 km) urban 12.8 · extra-urban 6.8 · combined 9.0; CO_2 emissions 212 g/km

PORSCHE

Issue 1/2012

Porsche Engineering Magazine

Use our drive.

911 (Type 991): fuel consumption (in l/100 km) combined 9.7-8.2; CO_2 emissions 229-194 g/km

About Porsche Engineering

At Porsche Engineering, engineers are working on your behalf to come up with new and unusual ideas for vehicles and industrial products. At the request of our customers we develop a variety of solutions – ranging from the design of individual components and the layout of complex modules to the planning and implementation of complete vehicles, including production start-up management. What makes our services special is that they are based on the expertise of a premium car manufacturer. Whether you need an automotive developer for your project or prefer a specialist systems developer, we offer our customers both because Porsche Engineering works successfully across both of these areas. The extensive knowledge of Porsche Engineering converges in Weissach – and yet it is globally available, including at your company's offices or production facilities. Regardless of where we work – we always bring a part of Porsche with us.

www.porsche-engineering.com

Dear Readers,

When we analyze our company's more recent projects, one thing is clear: sustainability and environmental concerns have changed demand behavior and have now become a driving force of technical innovation in many areas of automotive development.

Tighter political and legal regulations for the mobility of tomorrow play an important role in this. It seems to us, however, that another important factor here is the constantly changing values of automotive industry customers. This has a direct effect on clear trends in automotive development.

At the same time though, the "old economy" of automotive development, such as body construction and drive technology, is experiencing another renaissance. Lightweight construction has been an essential part of bodywork development for some time now. But the potential of combustion engines has also still not been fully exhausted yet.

The mobility of today and tomorrow is increasingly electric. With the hybridization of vehicles, we are experiencing a highly complex step towards electromobility. There has already been plenty of hard work on the further development of battery and electric vehicle designs, in order to increase operating distances without having to noticeably compromise the comfort of the vehicle user.

In order to contribute actively to these developments for our customers, we are continuously investing in our expertise and capacity at Porsche. Whether this is on a grand scale, such as the consistent expansion of the Weissach Development Center, or on a smaller scale, such as the operation start-up of new high-voltage and thermodynamics testing stands.

We invite you – not without pride – to take a look at this and other Porsche developments: Discover for yourself how Porsche is setting new standards in the areas of efficiency, lightweight construction, performance and emotions with the latest generation of the 911 Carrera.

If reading our magazine awakens your interest in developing something with us, then we look forward to working with you to meet the challenges you set us.

We hope you enjoy reading our first issue of 2012.

Yours, Malte Radmann and Dirk Lappe
Managing Directors Porsche Engineering

911 (Type 991): fuel consumption (in l/100 km) combined 9.7-8.2; CO_2 emissions 229-194 g/km

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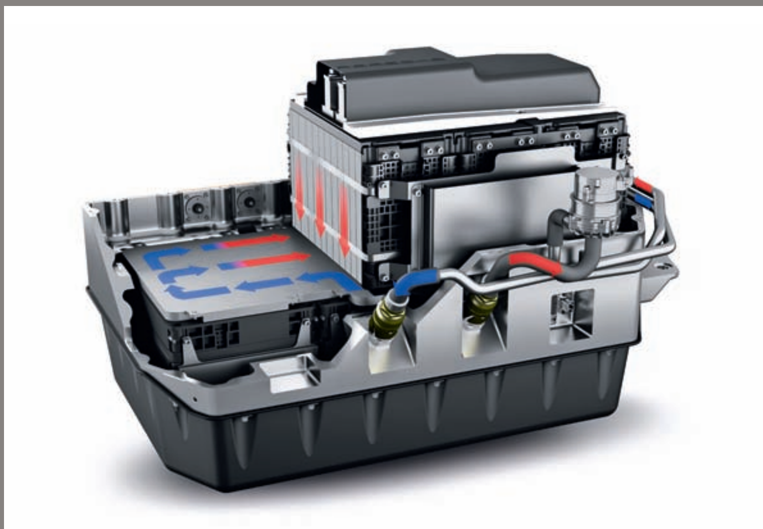
We develop the future, for example the seven-speed manual transmission in the new 911. Shift into gear for the future with us – what will you use our drive for?



Wolfsburg: Porsche Engineering grows

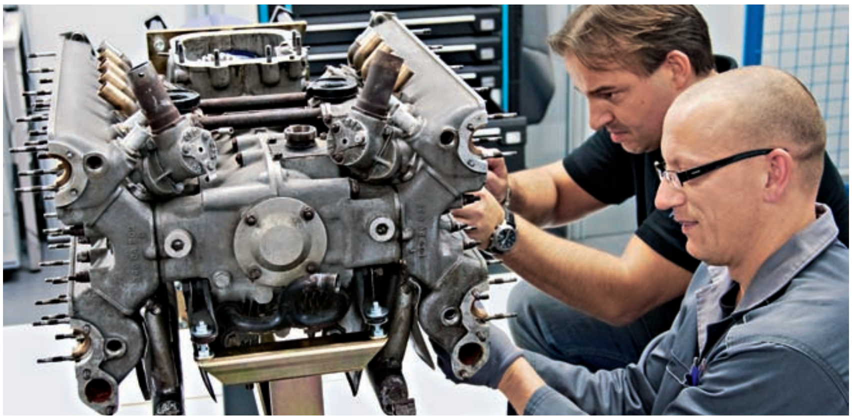
Thanks to continuing growth, activities at Porsche Engineering in Wolfsburg have been expanded. At the project office in Wolfsburg, there are not only specialists in the development of electric/electronic systems, but also first-class experts in the layout and development of modules, assemblies and complex components. The Wolfsburg office plays an important role in Porsche's projects for external customers and therefore contributes significantly to the integrated engineering services within the corporate group.

CURRENT NEWS

Porsche Engineering Prague: ten-year anniversary

Along with 80 years of Porsche engineering services, 2011 also marked the tenth anniversary of the Prague subsidiary of Porsche Engineering. The branch office in the Czech Republic is an integral part of engineering services by Porsche. It specializes in complex technical calculations and simulations, and has expertise that stretches way beyond the automotive industry to a wide range of areas and sectors. It was established after a successful partnership with the Technical University of Prague. Through the intensive and valueable collaboration between the industry and different fields of science, the latest results from scientific engineering research are also channeled into Porsche Engineering.

Milan Simadl, head of the commercial section of the German Embassy in the Czech Republic and Dr. Miloš Polášek, head of Porsche Engineering Prague, at the 10 year anniversary celebrations



Historical analysis

Porsche Engineering has carried out a detailed breakdown, analysis and documentation of the historical Type 360 “Cisitalia” engine on behalf of the Stuttgart-based Porsche Museum. The legendary Grand Prix racing car, completed at the Porsche engineering office in 1948, was technically way ahead of its time in many respects. By analyzing and examining the engine today, new data about the innovative technologies of the past can be gathered and a unique piece of documentation for automobile enthusiasts will be created.

QUALITY

Awarded

Porsche Engineering Group GmbH has once again successfully completed a quality management audit according to the industrial standard DIN EN ISO 9001:2008. The external auditor from the German Organization for the Certification of Management Systems (DQS) awarded the engineering services by Porsche a high standard of quality for its projects. Amongst other aspects, both the project management and the motivation of staff at the engineering services by Porsche was assessed as “very good”.

A Porsche to carry in your hand

A Porsche for travel, a Porsche for dinner and even a Porsche for the bathroom – rarely has the visual connection between the sports car and Porsche Driver’s Selection products been so close. This attractive product series, officially called “Porsche Travel System Soft Top Luggage”, is pure Porsche design. It includes items such as travel cases and bags in various sizes, a handbag, as well as a washbag manufactured in the same original soft-top material that is used for the folding tops of Porsche Cabriolets. “The idea to utilize this material for bags came about through working on the material for the soft-top of the Boxster Spyder and the corresponding marketing brochure,” explains Heidi Zink, project engineer for the Boxster Spyder.

The bags are available online at: ***www.porsche.com/shop***


PORSCHE
911 Carrera
S GO 4020

The most efficient and sportiest Carrera ever

Identity shaping in three digits: the new 911

THIS MODEL HAS BEEN THE GOLD STANDARD IN ITS CLASS FOR GENERATIONS. BUT NOW THE 911 SETS THE BENCHMARKS IN PERFORMANCE AND EFFICIENCY EVEN HIGHER – DEMONSTRATING ONE HUNDRED PERCENT PURE PORSCHE INGENIOUS ENGINEERING.

Cutting-edge technology in every area

The new 911 Carrera embodies the competence, passion and technological expertise of Porsche more than any other model generation. Four key development aspects define the new 911: lightweight construction, performance, efficiency and emotions. Porsche Engineering has also played a significant part in creating the new generation of the 911 by developing the new seven-speed manual transmission.

With the new generation of the 911, Porsche engineers have once again combined the latest technological developments in an exceptional way, in order to provide maximum driving pleasure and efficiency. This ingenious engineering is not just evident in the sports cars, but also in a wide range of engineering projects for external customers. Aspects like lightweight construction, performance, efficiency and emotions are increasingly playing an equally important role here as in the 911.

Efficiency

Lightweight construction throughout the vehicle and extremely economical engines in comparison to their output have always given the 911 Carrera an exceptional power-to-weight ratio and exemplary fuel consumption. The new generation differentiates itself from the competition even further in both areas: with a power-to-weight ratio of 4.7 kilograms per kW (10.3 lb per kW), the new 911 Carrera S clearly comes out top of its class. And in NEDC consumption, the 911 Carrera and the 911 Carrera S, each with Porsche Doppelkupplungsgetriebe (PDK), once again boast unmatched and exceptional figures, with 8.2 l/100 km (28.6 mpg imp.) and 8.7 l/100 km (27 mpg imp.) respectively.

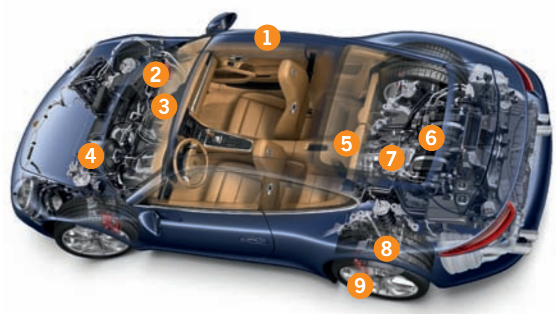
This huge step forward rests on the design: the entire new 911 Carrera has been designed for more efficiency, minimized rolling resistance and optimized operating strategies. The main basis for this efficiency is lightweight construction. The completely new aluminum-steel construction of the body not only enables the new model to be up to 45 kilograms (99 lbs) lighter than previous generations, but also ensures a weight advantage of more than 100 kilograms (220 lbs) over the lightest of competitors.

The mechanical components of the engines have been made even more frictionless, and to reduce consumption even more, vehicle electrical system recuperation and a map-controlled coolant thermal management system have been added. Through innovations and corresponding improvements in these two areas, Porsche has succeeded in reducing consumption in the NEDC by 0.45 l/100 km (522.7 mpg imp.). The efficiency target has also been achieved with the help of the first ever seven-speed transmission in automotive construction and the Porsche Doppelkupplungsgetriebe (PDK), also with seven speeds. Porsche Engineering led the development of the manual seven-speed transmission, working together with the transmission manufacturer ZF Friedrichshafen AG (see info box on pages 14/15).

The extremely impressive 911 Carrera and 911 Carrera S models are highly efficient with maximum performance

With the new 911 Carrera generation, Porsche has also further improved the fine details of the previous generation's exemplary aerodynamics. The basic building blocks of the aerodynamic design are the streamlined body surface, the new rear spoiler and the cooling system, which does not require large air intakes underneath the vehicle, thereby enabling the smoothest possible vehicle floor. The aerodynamically effective area of the rear spoiler was widened from 898 millimeters to 1,137 millimeters. It is extended automatically at 120 km/h (75 mph) and retracted at 80 km/h (50 mph), but can also be extended below these speed limits at the push of a button. Further aerodynamic improvements were secured by optimized air brake spoilers, aerodynamically optimized exterior mirrors, improved engine ventilation and optimized fairings on the front wheels.

Using the latest technology for more performance and efficiency



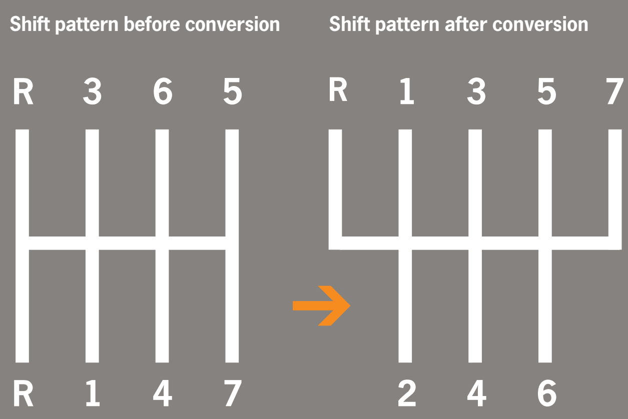
1. Lightweight structures
2. Low drag, variable aerodynamics
3. Start/stop function, coasting, on-board electrical system recuperation
4. Electro-mechanical steering
5. Drive train incl. seven-speed PDK/world's first seven-speed MT
6. Engine technology
7. Thermal management of engine + transmission
8. Reduced residual braking torque
9. Reduced tire rolling resistance

911 (Type 991): Fuel consumption (in l/100 km) combined 9.7-8.2; CO_2 emissions 229-194 g/km

Ingenious Porsche Engineering

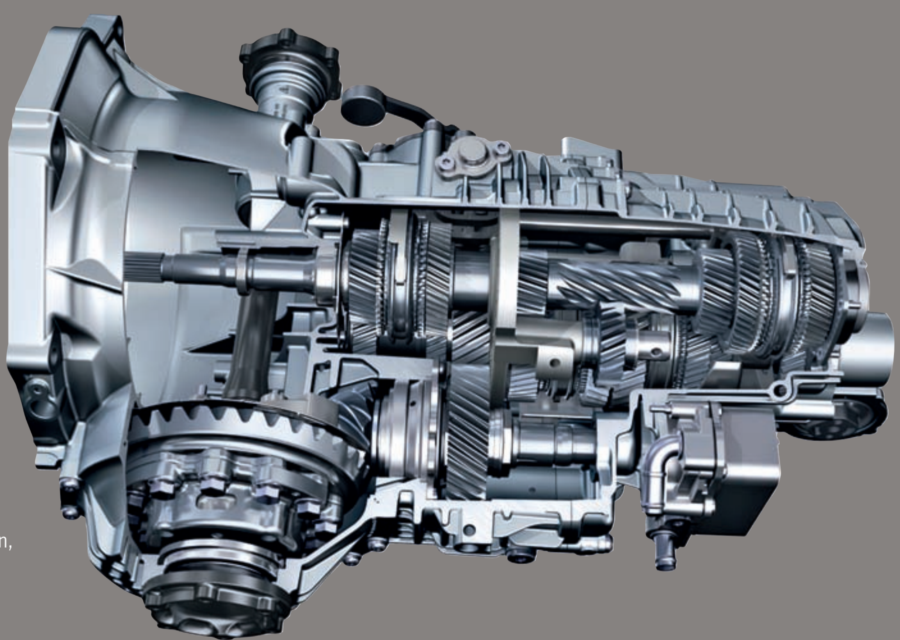
The development of the new seven-speed manual transmission

Porsche Engineering led the development of the world's first and only manual seven-speed transmission in the automotive sector, working together with the transmission manufacturer ZF Friedrichshafen AG. The new transmission was based on the Porsche Doppelkupplungsgetriebe (PDK). Taking the manual gear changes into consideration, the ratios of the third and seventh gears were modified in comparison with the PDK. The third gear has a higher ratio, which reduces consumption. The seventh gear has a lower ratio to maintain pulling power even at comparatively low speeds.

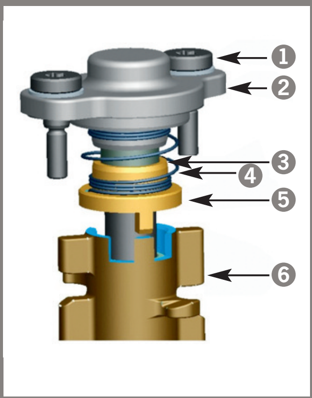


Shifting gears

Gears are shifted out via two cable winch mechanisms. One cable is for selecting the gear and the other is for shifting it. The transmission uses an H-shaped shift pattern. As the manual transmission is based on the PDK transmission, and neighboring gears (for example first gear and second gear) are not positioned directly opposite each other in the PDK transmission, a completely new internal gear shift had to be developed. The goal here was to covert the shift pattern to an H-shaped shift pattern with a new internal gear shift. The mechanism that enables this conversion is based on an invention by the company ZF Friedrichshafen AG.



The world's first ever seven-speed manual transmission, developed by Porsche Engineering



1. Fitted bolt
2. Cover plate
3. Flange bushing
4. Spring
5. Locking ring
6. Carrier shaft

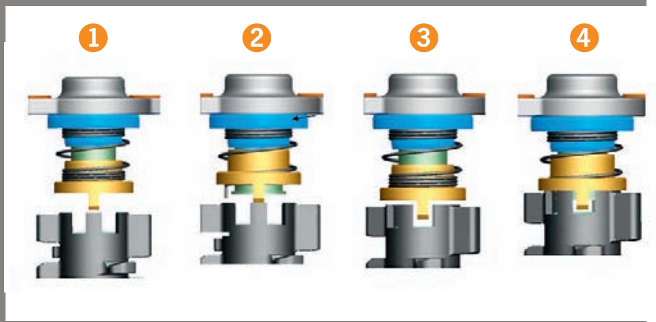


Figure 1
Gate 3/4 selected →
Locking ring is decoupled from the carrier shaft by 1 mm

Figure 2
Gate 5/6 selected →
Carrier shaft pushes the locking ring upwards and blocks gate 7

Figure 3
Shift into fifth or sixth gear →
Carrier shaft rotates by 29° → Locking ring moves back in axial direction and releases gate 7

Shifting out of fifth or sixth gear →
Carrier shaft rotates back to neutral position → Locking ring is radially pretensioned by the rotating spring

Figure 4
Shifting to gate 7 →
Carrier shaft pushes the locking ring upwards

Through this invention, any gear arrangement in the gear set of the transmission can be converted into an H-shaped shift pattern that is familiar and comprehensible for the driver. The main element of the gear shift is the carrier shaft, which can move translationally (in a straight line) and rotationally (turning). The carrier shaft's movement is transmitted to the cable winches outside it and transferred to the gears by the lever mechanism on the shift cover. In order to select a gear, the carrier shaft is pushed axially in the shift gear frame. The carrier shaft is then turned in order to shift gears. The shift forks are linked to the individual shift gear frames via the shift rods. Through the unique arrangement of the shift fingers on the carrier shaft, the shift gear frames of each gear are moved at the same time through this rotation during the shift from first gear into second gear.

Seventh gear shift lock

In order to prevent inadvertently shifting to seventh gear, a special shift lock was developed. That means that it is only possible to change into the gate for seventh gear if fifth or sixth gear was selected beforehand. However, the driver can shift back down at any time.

Martin Kuhn

In this way, like its forerunners, the new 911 Carrera characteristically combines exciting sportiness with exemplary efficiency. The formula for this: Porsche Intelligent Performance.

Performance

The proof of the 911 Carrera's performance gain speaks for itself: the new 911 Carrera with optimal sporty equipment can lap the Nürburgring's Nordschleife in 7:40 minutes – 14 seconds faster than the previous model.

The overall design of the new 911 Carrera provides the foundation for this significant improvement in performance. The lengthening of the wheelbase by 100 millimeters and the wider front track width alone – 46 millimeters wider in the 911 Carrera and 52 millimeters wider in the 911 Carrera S – results in completely new vehicle geometry with even more driving stability at high speeds, when on the straight and when cornering.

The second main reason for improved performance is the new drive unit. Both engines, with 3.5 liters and 3.8 liters displacement, have been designed according to motor racing principles for high revs. The maximum engine speed of the six-cylinder engines has been increased by 300 rpm to 7,800 rpm. The entire intake manifold has also been optimized. The intake air flows through flow-optimized channels, new multi-hole injectors inject the fuel more efficiently and exhaust emissions exit the 911 Carrera through a system with reduced backpressure. The fine-tuning of the aerodynamics has succeeded in reducing the total lift (C_A) of the new 911 Carrera models by 0.02, to a mere 0.05.

Even more agility in the new 911 Carrera is provided by Porsche Torque Vectoring (PTV). This system consists of a mechanical limited-slip rear differential and variable torque distribution to the rear axle.

For the first time ever, Porsche has used electro-mechanical power steering developed from scratch for the new 911 Carrera. This also has a tangible effect on performance: When braking on road surfaces with different levels of grip, a tug on the steering wheel imparts a steering input in the desired direction, making it easier for the driver to stabilize the vehicle and keep it in the desired lane.

Porsche identity: the unmistakable performance of the new 911

Another decisive contribution to the impressive increased performance of the new 911 Carrera is provided by the entirely newly developed optional Porsche Dynamic Chassis Control (PDCC). The intelligent control of the PDCC system is, for example, able to exercise individual control over the hydraulic actuators, depending on the driving situation, influencing self-steering behavior in the process and consequently improving vehicle stabilization.

Lightweight construction

With the new 911 Carrera, Porsche sets new standards in lightweight construction. Up to 45 kilograms less total weight than the previous generation means a total weight reduction of 98 kilograms in the basic vehicle design. The reason for this difference: increased safety requirements, a longer wheelbase, fuel consumption reduction measures and a more powerful product firstly led to a weight increase of around 58 kilograms in comparison to the previous models.

The key to success was lightweight construction throughout the vehicle. For the first time in the new 911 Carrera, an aluminum-steel body construction has been used. The underlying idea of this design

The targeted use of a wide range of materials has resulted in a significant reduction in weight

is using the right material in the right place. The extensive use of aluminum to reduce the vehicle's weight is therefore balanced with elements of steel of varying degrees of strength for a more rigid body and optimum occupant protection.

Parts that are especially important for passive safety, such as the inner roof frame and the B-pillar, have been made in ultra high-strength, boron-alloyed steels. The new modular roof design also provides advantages in terms of weight. For the series model without a sliding roof, the steel outer skin of the roof has been replaced with significantly lighter aluminum.

The drive train, chassis and electrical equipment have all also been comprehensively redesigned to be lighter. The chassis accounts for more than five kilograms of weight reduction, mostly thanks to the newly constructed front axle with compact lightweight suspension strut.

Emotions

A highlight of the 911 design is the leather interior of the vehicle. Typical Porsche styling meant that the engineers were faced with quite significant challenges. Engineers at Porsche Engineering contributed to the development and implementation of the overall leather design by designing the instrument cluster and the center console as well as the carpet-covered elements. Specifically, they were responsible for creating a strategy for component and tolerance layout and for carrying out covering tests. Managing system and component suppliers and cooperation with the Porsche leather manufactory were also an important part of their job.

The driving experience in the 911 is defined by the design, the sound and the vehicle providing feedback from the road to the driver through shifting gears and revving the engine. The driver experiences real driving pleasure when he feels the performance of the vehicle directly. The main communicator of this is the sound. Mechanical engine sounds are characterized by higher frequencies and have tonal elements.

The basis of the sound design for the air intake and exhaust systems in the new 911 Carrera was created in the very early stages of the vehicle's design. The layout and dimensions of the manifolds, pipes, catalytic converters and mufflers were all visually illustrated and evaluated with the help of a computer model before there was even any hardware.

The development of muffler systems is one of the core competencies at Porsche and is always carried out at the Weissach Development Center. In order to allow the driver to feel the revs and the power of the engine, the pathways of the air intake and mechanical engine sounds are tuned so that messages from the new 911 to the driver are transmitted in as pure and unadulterated form as possible in all driving conditions.

Like no other sports car, the new 911 Carrera shows that by combining the latest cutting-edge technology, exceptional performance and the highest efficiency can be achieved at the same time. Porsche engineers love the challenge of reaching ever higher levels of performance – whether in a sports car or in an external customer project. There's a bit of 911 in all Porsche Engineering projects.

Porsche Engineering contributed to the development and implementation of the leather interior design

Out in the open

The 911 Carrera Cabriolet debuts an innovative new roof design

The new open-top models of the 911 Carrera and the 911 Carrera S also belong to the new generation of the classic 911 sports car – the open-air season can begin.

With its completely newly developed and unique roof design, the Cabriolet continues what the Coupé began with its new aluminum-steel body. The typical 911 roof contours have been entirely preserved for the first time. Intelligent lightweight construction, which also includes the use of magnesium for the construction of the convertible top, has ensured less weight and more sportiness, as well as lower consumption and greater comfort. Porsche has managed to reverse the weight spiral for all convertible 911s and has managed to make the new Cabriolet models significantly lighter than their predecessors.

Both new Cabriolets have the same drive system as the Carrera Coupés. A 3.4-liter boxer engine with 257 kW (350 hp) operates in the rear of the 911 Carrera Cabriolet, and its power is transmitted to the rear wheels by the seven-speed manual transmission. The open-top 911 Carrera S has a 3.8-liter six-cylinder engine with 294 kW (400 hp) and also comes with a seven-speed manual transmission as standard. The convertible 911s also differentiate themselves strongly from the competition in another way: in the NEDC both models consume less than ten liters of fuel for 100 kilometers (23.5 mpg imp.). Alternatively, Porsche Doppelkupplungsgetriebe (PDK) can also be optionally selected for the Cabriolet models, which makes even lower fuel consumption and shorter acceleration times possible.

The longer wheelbase compared to the previous model, the wider front track at the front axle and the new electro-mechanical power steering give the new Cabriolets even sportier driving characteristics, more precision and increased agility. On top of that, additional active control systems are available as standard or as an option depending on the model, which will improve driving dynamics even further.

High voltage: 300 kW source/drain

The high-voltage battery is the heart of electric and hybrid vehicles. When developing high-voltage batteries, testing the battery with predefined profiles in both quadrants i.e. when charging and discharging requires special attention. Porsche Engineering has developed a special high-voltage infrastructure for testing a diverse range of batteries and cell modules.

Electrical characteristics

Since the end of 2010, Porsche Engineering has been using a so-called "direct current source/drain" with a maximum capacity of 300 kW for the operation start-up of high-voltage batteries developed in-house.

In its function as a source (first quadrant), it is possible to charge the battery in constant-current and constant-voltage modes. When it is used as a drain (second quadrant), it fully replicates the power electronics, including the drive motors, which consume large amounts of power. An interesting side effect is that the power taken from the battery can be fed back into the power grid.

Thermal characteristics

Since 2011, Porsche has also been using a thermodynamics test stand. This provides the batteries with the right temperature by means of air, coolant or refrigerant.

By using the thermodynamics test stand, all battery types with various types of cooling systems can be tested and started up. There is also the option to simulate extreme thermal conditions in the upper limits of what the battery can withstand, for which the battery can also be preconditioned.

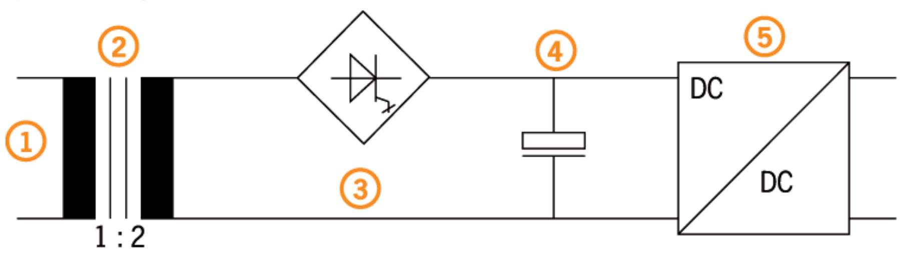
Particular electrical characteristics

• DC output voltage range:	8 to 800 volt
• DC output current range:	+/800 amps
• Power range:	up to 300 kW
• Power factor:	0,99
• Efficiency at 300 kW:	91%
• Voltage tolerance:	+/–1%/current tolerance 0.3%
• Controllable using a CAN control unit	
• Short-circuit resistant	

Particular thermal characteristics

• Coolant temperature management:	20 kW cooling and heating power
• Coolant temperature:	5 to +105 degrees Celsius
• Coolant flow:	3 to 60 liters per minute at maximum operating pressure of 4 bar
• Refrigerant cooling:	up to 15 kW with R134a
• Air cooling:	1,000 liters per second at 5 to +80 degrees Celsius

Simplified diagram of the source/drain



1. AC input
2. Transformer
3. Controlled rectifier
4. 800 volt intermediate circuit
5. Bidirectional buck/boost converter

The source/drain is connected to the three-phase current (see point 1 in the figure on page 19). The AC voltage is doubled via a transformer (see point 2). A controlled rectifier (see point 3) converts the AC voltage into a direct voltage of 800 volt DC. A capacitor forms the intermediate circuit, and typical voltages can be simulated using a bidirectional, buck/boost converter.

The system has two separate current controllers. These enable the extremely dynamic control of the current with adjustable low-voltage and surge protection settings.

The battery under test and the testing facility are physically separate and are controlled from a control room. The testing chamber is also equipped with an array of safety mechanisms.

Using the testing facility

The facility is used for the operation start-up testing and design verification of prototype batteries. After checking their component arrangement, a series of electrical and thermal safety tests can be carried out. This includes a fatigue test and the classification of different batteries.

Operation start-up of the Battery Management System (BMS)

Starting up a high-voltage battery system firstly requires the calibration of the Battery Management System in order to check the basic system functions. The cell voltage in the cell controllers, the activation of the contactors, the management of charging and discharging, and the thermal management are all checked one by one in this process.

Through an iterative process, the resistance- and temperature-dependent parameters are defined (for example temperature-dependent electrical charging and discharging limits). The electrical sensor in the battery and the state-of-charge (SOC) BMS algorithms, which are extremely dependent on cell chemistry, are tested using an external power measurement and Coulomb counting device.

Design verification

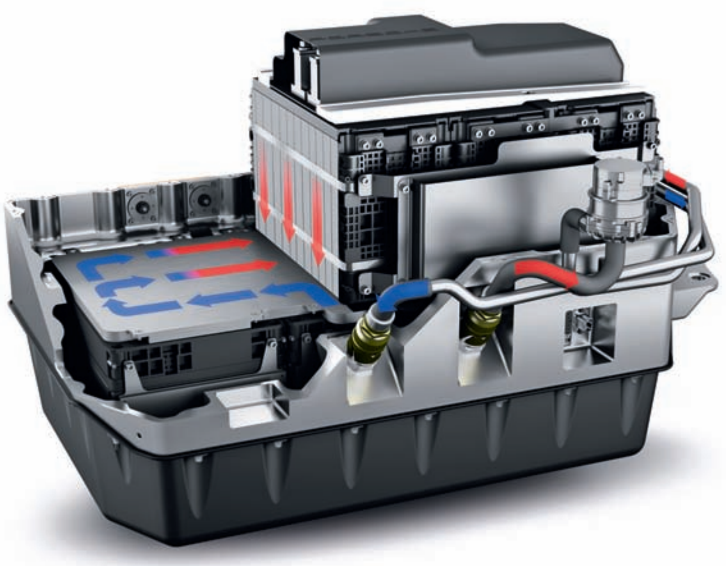
Based on electrical load profiles and the necessary minimum capacity of the power storage unit, the battery cells are selected and the high-voltage power circuit and the thermal circuitry in the battery system are designed. For this the temperature measurement points, which optimally define the thermal state of the battery, also have to be laid out.

Electrical and thermal design characteristics are significantly defined by the basic electrical power capacity, safety and reliability, and the lifespan of the power storage system.

In order to make sure that the design of the system is correct, a combination of various testing methods is used. Using synthetic load profiles, the characteristics of the electrical and thermal circuitry can be established.

The internal resistance of the battery system can be precisely measured. By allocating internal resistance parts and various system components (cells, cell connectors, busbars, etc.), potential areas for optimization can be precisely identified.

The testing and optimization of the control strategies of the BMS for thermal management and the approval of power/voltage limits are generally carried out using load profiles, which are based on real driving cycles.



Cross section of the high-voltage battery in the Boxster E research vehicle, which was tested thoroughly on the high-voltage testing stand

Typical safety test cases

1. Testing of the BMS deactivation function: Charging or discharging power above the maximum permitted limit is fed in or out. This tests whether the BMS disables the contactors within the required time frame.
2. Precharging against a short-circuit: The facility is configured for a short-circuit. The precharging algorithms in the BMS must recognize this situation and log a fault. The main contactors must not be activated.
3. Insulation resistance: a defined parasitic resistance is connected between the chassis and the negative terminal of the battery. The BMS must clearly detect this.
4. Overcharging protection: The battery is charged until it has reached end-of-charge voltage. During the constant-voltage phase a higher voltage is fed in carefully. The BMS must disable the contactors.

Safety tests

High-voltage batteries and conventional batteries must fulfill the highest safety standards. In particular, the high voltage of the battery requires a high level of insulation resistance against the chassis of the vehicle at both terminals. High load profiles also result in significant power dissipation in the battery, which in turn leads to it heating up. During safety tests, derating functions including deactivation are checked by conditioning the battery and running it through load profiles. These are then mapped in hardware-in-the-loop test vectors, which were developed especially for this purpose by Porsche Engineering. Typical safety test cases can be seen in the table above.

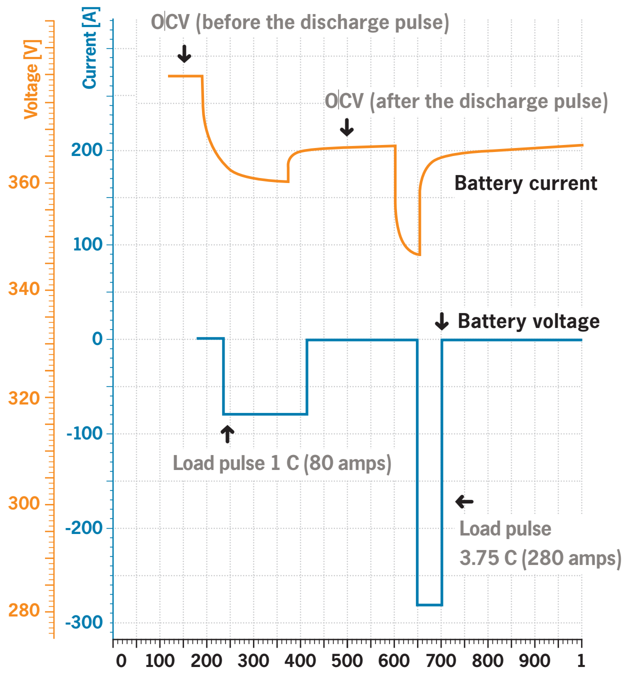
Classification/fatigue testing

Along with testing the perfect construction of the battery with the naked eye, the battery is also the subject of targeted testing for hidden thermal and electrical resistance at its source/drain. Above all this makes sense in endurance tests and the testing of electric vehicles, in order to attain a precise description of the current state of the battery during every revision. As part of the Boxster E research project, for example, (see issue 01/2011 of the Porsche Engineering Magazine), the internal resistance of the battery was repeatedly tested on the cell level, thereby identifying the health of the battery (see figure "State of Health" below).

Porsche Engineering integrates expertise from various areas for the development of high-voltage batteries. With individual tests and analysis tailored for customer requirements, Porsche Engineering can provide engineering services for diverse projects, from an electric scooter to a fully electric sports car all according to the principle of Porsche Intelligent Performance.

Emmanuel Dhollande, Volker Sonn, Björn Pehnert

State of Health



Analysis of internal resistance using pulse discharging provides precise data about the state of health of the battery

Weissach is growing. And so are the engineering services by Porsche.

With extensive construction projects, Porsche is now implementing a long-term strategic site plan for its research and development center in Weissach. The sports car manufacturer is investing around €150 million in a high-tech wind tunnel, a state-of-the-art design center, and an innovative electronics integration center. This means one thing above all for engineering services by Porsche: first-class resources for demanding projects.

New high-tech wind tunnel

With the new wind tunnel, Porsche is equipping itself to be able to fully meet and overcome the technological challenges involved in automotive development in the future. “Good aerodynamics makes an important contribution towards lower fuel consumption and better performance – which are both important aspects of implementing Porsche Intelligent Performance,” explains Wolfgang Hatz, board member in charge of research and development at Porsche AG. These new facilities will help Porsche to maintain its top position in the field of aerodynamics and to further extend its lead.

Cutting-edge design studio

Outstanding design has always been one of Porsche’s strongest areas of expertise. Above all, the new studio will provide more space for the Porsche designers, who are closely involved in the earliest concept phases of every vehicle development process. Due to an increased workload, greater capacity for sports car construction is urgently needed at the Weissach center of competence.

An electronics integration center for the future

In the new electronics integration center, various subdivisions that had previously been scattered across several buildings at the Weissach site belonging to Porsche can be bundled under one roof. Working in close proximity is a major advantage. Especially in electronics, which now plays a role in almost every vehicle component, the close interaction between different electrical system/electronics experts from related specialist fields during development contributes significantly to the success of projects. With the new electronics integration center, Porsche is creating the optimum conditions for its objective to “continue developing electric and hybrid technology,” according to Hatz.

As the facility will not just be used exclusively for development work by Porsche,

but will also continue to be available for Porsche projects with external customers, it can be accessed directly from the design center located beside it, but also has its own entrance for the discreet fulfillment of confidential customer projects.

Prepared for the future

The comprehensive range of resources already available for external customer projects at the Weissach Development Center today is now being invested in and expanded significantly.

“The symbiotic connection with the Weissach Development Center is a unique feature of Porsche Engineering in the automotive sector,” says Malte Radmann, managing director of Porsche Engineering. With the development center’s unique and high-tech infrastructure, Porsche Engineering will continue to be able to provide the optimal conditions for engineering services projects in the future.

WEISSACH MILESTONES

16 October 1961	Work begins on the test track (construction of the skid pad)
1967–1970	Construction of circuit and “rough-road” track facilities for further testing purposes
1969	Construction of additional testing stands, workshops, and facilities for experiments; the cornerstone of today’s Weissach Development Center
1974	Construction of an office building in the shape of a hexagon, which provides the ideal layout for close cooperation and teamwork
1982	The Environmental Technology Measurement Center moves into building 26 (with testing stands that will fulfill regulations for decades to come)
1983	Construction of testing building for engines and units
1986	Inauguration of the most modern wind tunnel of its time with the best possible air flow quality and completion of the crash testing facilities
2002–2004	Completion of additional office buildings and the tire center (testing facility for fatigue and brake tests)
2007	Opening of a four-story drivetrain center (a combined workshop and office)
2011	Construction begins for the long-term strategic site plan with a high-tech wind tunnel, state-of-the-art design center, and electronics integration center for the future

Keeping cool in future

Due to new alternative drivetrain designs for the vehicles of today and tomorrow, the entire basis of vehicle interior climate control is changing. Porsche Engineering is therefore ensuring that an integrated thermal management system is being developed now.

Some factors that influence the climate of the vehicle interior

Physical factors

- Air temperature
- Relative humidity
- Thermal stratification, vertical/horizontal
- Thermal radiation
- Air circulation
- Air quality
- Atmospheric electricity
- Acoustics
- Visual factors
- Number of passengers
- Seasonal changes to important physical factors

Physiology

- Physical constitution
- Sex
- Age
- Ethnic factors
- Food intake

Subjective factors

- Clothing
- Level of activity
- Level of acclimatization
- Daily/annual rhythm

➡ **"Comfort is the absence of disturbing factors"**

Comfortable vehicle climate

Customers today expect a comfortable temperature in the interior of their vehicles – regardless of the conditions prevailing outside. Multi-zone climate control units in the front and back, provide the option to create a comfortable climate for each passenger, as is the case, for example, with the Porsche Panamera's state-of-the-art optional Four-Zone Climate Control.

A moderate interior climate, or "comfort" in the vehicle, can be basically reduced to the "absence of disturbing factors". The factors influencing this sense of comfort can be subjective as well as physical or physiological.

Along with creating and maintaining a comfortable vehicle interior climate through cooling and/or heating it, climate control must also fulfill legislative and safety requirements. This includes de-icing the windshield and windows within a defined time (for example, when cold-starting in the winter) and keeping the windows free from condensation.

It is also important to remember that the driver's reaction capabilities and concentration in difficult situations will be better the more comfortable he or she feels. This means that the temperature must be right from head to toe (what is known as stratification: "a cool head and warm

Panamera: fuel consumption (in l/100 km) combined 12.5-6.3; CO_2 emissions 293-159 g/km

The optional Four-Zone Climate Control in the Porsche Panamera enables individual, targeted climate control

feet"). The air distribution, cleanliness and humidity must also be exactly right.

How a conventional climate control system works

Basically there are three main operating modes for the climate control system in a vehicle:

- **Pure heating mode:** quickly heating the cold interior of the vehicle in winter and de-icing the windshield when temperatures outside are low.
- **Combination mode:** automatic control of the vehicle climate ("car climate 22 degrees Celsius"/71.6 degrees Fahrenheit). Additional fresh air is first dehumidified and is then brought to the right temperature, to keep the windshield and windows free from condensation. This combined mode is the most common one for climate control systems in Central Europe, due to the climate conditions there.
- **Pure cooling mode:** quickly cooling the warm vehicle interior of the vehicle in summer, when temperatures outside are high.

A conventional vehicle climate control system design consists of the following components in addition to the actual climate control unit: a refrigeration circuit (provision of cold air) and a cooling circuit (provision of warm air), air ducts with outlet vents, a climate control operating unit and a climate control device (with its corresponding electrical parts such as a cable harness and sensors, for example).

The climate control unit measures the conditions outside as well as the current conditions in the vehicle interior and compares them with the target requirements. Thus, the climate control system can achieve the required climate using the three modes. Targeted individual climate control can be achieved in this way, which the two-zone automatic climate control system of the new Porsche 911 is capable of, for example.

These are the basic customer requirements and expectations for future climate control systems, regardless of the drive unit design of the vehicle.

Factors that influence vehicle climate control system designs

Climate control in vehicles is influenced by many different factors. These include the size of the passenger space, the design of the dashboard, the size and angle of the windshield, the thermal mass that needs to be climate controlled, the exterior aerodynamics and thermal management in the vehicle. All of these factors are taken into account and checked in the early stages of vehicle development, before the climate control system is designed, as their effects can vary widely depending on the vehicle in question.

How a conventional refrigeration circuit works

The most important parts of a climate control system are the refrigeration and cooling circuits. While the refrigeration circuit provides the energy to cool down the vehicle, the cooling circuit for the combustion engine collects the energy for heating up the vehicle interior.

Refrigerant sucked in by the compressor circulates in the refrigeration circuit. This circuit is divided into two sections: a high-pressure and a low-pressure section. The refrigerant, in the form of a gas, is heated in the compressor by being compressed and then channeled through the condenser under high pressure. There, heat is absorbed from the hot gaseous refrigerant, leading to a liquefaction of the gas.

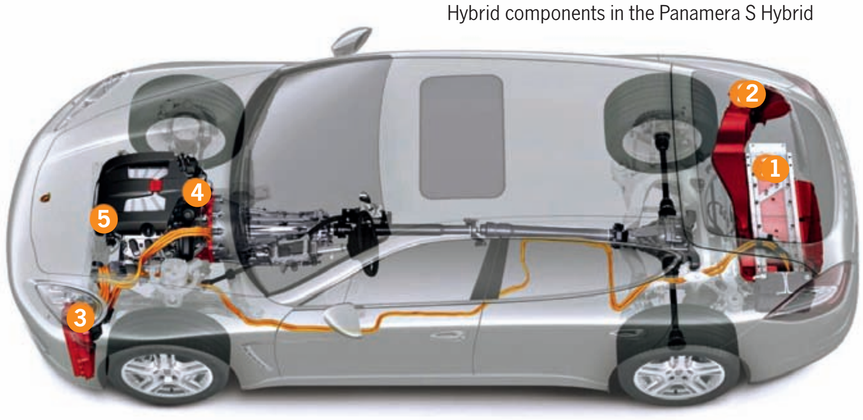
911 (Type 991): fuel consumption (in l/100 km) combined 9.7-8.2; CO_2 emissions 229-194 g/km

Then the refrigerant enters the drier/collector. In order to protect the refrigeration circuit from damage, impurities and water are separated from the refrigerant in the drier. The refrigerant is then passed from the drier to the expansion valve and enters the evaporator in a mostly liquid form. There it is vaporized by absorbing heat. Because it has absorbed heat from the surrounding environment, the air is cooled and dehumidified. The moisture created by dehumidifying the air is taken away via tubes. On very humid days, this moisture can appear in the form of a puddle under the vehicle. In the low-pressure section, the gaseous refrigerant is sucked back into the compressor and the cycle begins all over again.

Future challenges

In conventional drive unit designs sufficient „free“ energy for a comfortable climate inside the vehicle is available in form of „waste heat“ from the combustion engine. With alternative drive unit designs such as those in electric vehicles, however, the energy for heating the vehicle must be additionally generated. The efficiency of the individual electrical components is significantly higher in electric vehicles than in combustion engines. The missing energy in the form of heat that must be electrically generated in vehicles with electric vehicle drive units means that there is less energy available to propel the vehicle. The challenge therefore consists of maintaining a comfortable climate in the vehicle interior with as little energy as possible, in order to affect the vehicle's driving range as little as possible.

Hybrid components in the Panamera S Hybrid



1. High-voltage nickel metal hydride battery
2. Air supply duct
3. Power electronics
4. Hybrid module
5. Supercharged 3.0-liter V6 engine

Hybridization

Vehicles with hybrid drive units have a conventional combustion engine supported by an electric motor. Electric power is stored in a battery, which also must be kept cool. In the Panamera S Hybrid, the high-voltage nickel metal hydride battery is cooled by air. The challenge for the climate control system in a vehicle with a hybrid drive is the additional cooling required for the electrical components such as the battery, power electronics and the electric motor. As hybrid drives also usually have a start/stop function and can drive a certain distance on electric power alone, the climate control system must be designed so that it can operate without a combustion engine.

This means that the refrigeration and cooling circuit components, such as the compressor, must be powered electrically and can no longer be mechanically linked to the combustion engine, in order to ensure that the climate control system still functions when the vehicle has stopped at traffic lights, for example. This is made possible by special evaporators, which can store the cooling energy for a certain period (storage evaporators), and by high-voltage PTCs for electrical heating. Another major challenge for climate control and thermal management system design is ensuring that the drivetrain heats up quickly in order to reduce fuel consumption and emissions.

Electric vehicles

Electric vehicles – like the Porsche Boxster E research vehicle – use batteries that require a temperature range of between 20 and 30 degrees Celsius (between 68 and 86 degrees Fahrenheit) in their drivetrains. This temperature range ensures that the batteries function properly and prevents them from “getting old” too quickly. This means that the batteries do not just need to be cooled down, but sometimes also warmed up, depending on ambient temperatures.

Cooling with air, which is currently the standard method in hybrid drives, is no longer sufficient and must be replaced with liquid cooling methods using appropriate refrigerants or coolants. Climate control and thermal management are therefore becoming more complex and require new thinking.

The aim of the thinking behind the new designs at Porsche Engineering is to reduce the amount of heating required in the vehicle. There is potential in improved insulation, which will result in the loss of less heat via the body and the windows, and the reduction of the thermal mass to be heated in the vehicle's interior.

Batteries like those in the Boxster E research vehicle need to be warmed up as well as cooled down, depending on ambient temperatures

Innovative solutions

Options for new climate control system design being considered strongly at Porsche Engineering are the use of auxiliary heating systems (such as heat pumps, electric auxiliary heaters, fuel-powered auxiliary heaters) and targeted climate control according to the number of passengers in the vehicle. Other areas being focused on are the use of thermal storage systems, the preheating or precooling of the vehicle interior while the vehicle is being charged at the electrical power outlet, or the use of direct and surface heating devices in the seats and the steering wheel.

The cooling agents and cooling and heating methods are selected by engineers in the earliest stages of the design process. For this purpose, Porsche Engineering has developed its own thermal simulation tool, which was validated by tests. This can be used to work out and define the optimum climate control and thermal management system design at an early stage of vehicle development, using previously identified performance data, cooling and heating needs, and driving profile requirements.

Conclusion: challenges and solutions

Climate control and thermal management play a very important role when designing hybrid and electric vehicles, as the increasing electrification of vehicles leads to a decrease in the number of available sources of heat. As a result, today's standard method of reusing the (free) engine waste heat is becoming increasingly difficult or even impossible.

The more effective use of heated or cooled air in the vehicle interior, better insulation and further modifications in the vehicle contribute to reducing energy consumption for the heating and cooling of the vehicle interior. The same is true for the inclusion of new components in climate control and thermal management system design. Along with cooling the batteries in order to increase their lifespan, heating the batteries is also becoming more important.

Porsche Engineering is developing solutions for these challenges based on comprehensive electromobility experience from internal and external engineering projects, as well as thermal management expertise from classic sports car design. Using all the tools available to them, from simulation and calculation tools to component testing on test stands and the testing of entire vehicles in the climate wind tunnel and on the test track, engineers at Porsche Engineering are creating the climate control and thermal management system designs of the future.

Sebastian Ost, Michael Müller, Patrik Gisch

Panamera S Hybrid: fuel consumption (in l/100 km) urban 7.6-7.4 · extra-urban 6.8-6.6 · combined 7.1-6.8, CO_2 emissions 167-159 g/km

Who developed it? Porsche.

Around 20 projects from 80 years of engineering services by Porsche were exhibited in the Porsche Museum

For more than 80 years, Porsche has been globally active as an engineering services provider for external clients. Engineering services are an essential part of the Porsche brand core, and some of its most interesting developments were presented in the Porsche Museum.

"In the special exhibition '80 Years of Engineering Services by Porsche', the Porsche Museum and Porsche Engineering presented a selection of exciting projects and in this way, we have built a bridge from the past into the future," says Achim Stejskal, head of the Porsche Museum. "As an engineering services provider, Ferdinand Porsche and his team have established an international reputation for excellence – thousands of customer projects have been completed since the foundation of the engineering services office in 1931."

A large number of invited guests and former Porsche employees, including racing legends Herbert Linge and Peter Falk, attended the opening celebrations of the exhibition, which ran from June 21 to September 11, 2011 in the Porsche Museum.

"The engineering services by Porsche are the oldest business segment in the Porsche company. When the company was founded, there were no plans to build its own sports cars yet," says Stejskal. And so, as part of the special exhibition, around 20 special exhibits were on display, ranging from the development of entire vehicles, through engines and transmissions, to extraordinary industrial projects in the present.

One of the exhibits was one of the first ever Porsche development projects, which was contracted to the engineering office by the Wanderer automotive manufacturing company in Chemnitz in 1931: the Wanderer W 22, also known as Model 7 in the internal classification system created by Porsche. The mid-size sedan W 22 was well-known for its six-cylinder, light-alloy engine with 1.7 or 2.0 liters displacement, which would later also power the famous Audi Front.

Two years later, Auto Union contracted the design of a Grand Prix racing car – one of the most legendary racing cars of all time. Driven by racing heroes like Hans Stuck and Bernd Rosemeyer, the Auto Union "P-Rennwagen" achieved no less than 30 Grand Prix victories and 15 world records between 1934 and 1937.

One of the first ever engineering services projects by Porsche: the Wanderer W 22 from 1931

Above: Porsche engineers developed a bobsled for the professional sportsman Georg Hackl

Left: Porsche Engineering developed a new engine for the V-Rod model by Harley-Davidson

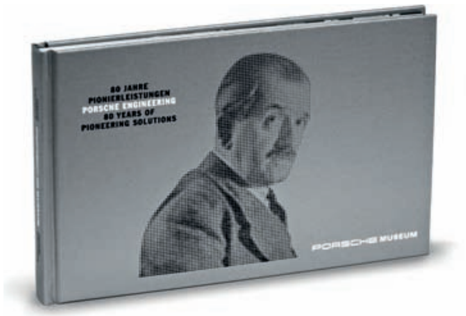
Thinking outside the box: Porsche was contracted to design the Opel Zafira for Adam Opel AG

The Opel Zafira compact MPV, designed by Porsche in 1994 for Adam Opel AG, was also exhibited, along with the Mercedes Benz 500 E, the series production of which was even carried out in the Porsche factory in Zuffenhausen between 1990 and 1994.

The anniversary exhibition, the most elaborate special exhibition to date in the museum, also surprised visitors with many unusual Porsche development projects from outside the automotive sector: along with a Harley-Davidson V-Rod and the sports watercraft Seabob, the Porsche Museum also showed an original bobsled developed by Porsche engineers in collaboration with the professional sportsman Georg Hackl. The Olympic sledding champion apparently wanted to see for himself how his Porsche bobsled was being exhibited at the "80 Years of Engineering Services by Porsche" exhibition – and so honored the Porsche Museum with a personal visit. Hackl won the silver medal at the 2002 Olympics in Salt Lake City with that very sled. Another unusual exhibit was the Adventure electric, full-suspension wheelchair, which was designed by Porsche in 2004 for the company Ulrich Alber GmbH.

"80 Years of Engineering Services by Porsche" was a unique exhibition: first-time guests, car lovers and technology enthusiasts alike marveled at astonishing engineering projects for external customers, some on show for the first time ever. The exhibition organizers were more than happy with the positive response: with around 90,000 enthusiastic visitors, the special exhibition for the 80-year anniversary of Porsche engineering services was a complete success.

Around 90,000 visitors marveled at the variety of Porsche developments



A compact history: the history of engineering services by Porsche, including lots of background information and additional pictures, is available as the anniversary special edition "80 years of pioneering solutions - Porsche Engineering" from bookstores and the museum shop at the Porsche Museum in Stuttgart-Zuffenhausen (ISBN 978-3-9812816-8-2).

Smoother control using robotics

Requirements for vehicle drivetrains are constantly increasing, especially with regard to the comfortable start-up of vehicles with manual clutches. In order to efficiently analyze the clutch characteristics (clutch engagement and start-up characteristics) and to be able to reproduce these results, Porsche Engineering has developed a unique clutch robot in collaboration with the Münster University of Applied Sciences (Automation and Robotics department).

Robotic systems have been used in vehicle pedal operation testing for some time now. The existing systems present various problems, however. Because they require external sources of power and lots of space for their computer hardware, in most cases they are used only to simulate distance profiles on roller dynamometer test stands. Using these systems for vehicles actually driving outdoors is basically impossible. Furthermore, only open-loop control but not closed-loop control is possible for these systems, and the pedals cannot be positioned precisely so that conditions can be reproduced. They are therefore not very useful for the analysis of clutch engagement characteristics. For this reason,

Optimum analysis of clutch characteristics

Requirements

- Compact setup for the hardware and the power source, so that the system can also be used in vehicles without much space in the interior
- Simple assembly of the system without having to modify the seat or the driver's footwell in all vehicle classes
- Logging of variables to be measured in real time
- Logging of pedal positions independently of the dynamics of the driver's seat
- Definition of the pressure placed on the pedal independently of the position of the robot
- Operation of all three pedals by the robot
- Highly dynamic processes that can be reproduced exactly (e.g. snap starts/racing starts)

Porsche Engineering has developed a new clutch robot that solves these problems (an overview of the requirements it had to meet is shown in the information box above).

Hardware configuration

The main unit of the clutch robot consists of aluminum plates, which can be modified to fit the shape of the driver's seat and the interior of the vehicle. In the main unit, three independent, closed-loop controllable linear motors are used to operate the three pedals.

The motors are connected to the pedals via adapter plates and a coupling bar that can be adjusted in length, and the pressure on the pedals is measured by a load cell integrated into the coupling bar. The pedal position is detected by cable pull sensors, which are fixed firmly in the footwell of the driver's seat and can therefore be used for position control without influence by the seating dynamics.

After the main unit has been fitted in the vehicle, a head unit is mounted on top of it. The three motors are then connected directly to the head unit via a docking connecter, so that there is no need for extra cables when setting up the robot in the vehicle. The controllers for the motors, and the computer system with a real time operating system (RTOS) and sensor signal processing, are located in the head unit. The external sensors, such as the cable pull sensors or the vehicle CAN bus, can be connected to the system with standard connecters.

Power is provided by a separate block and is connected to the head unit via a cable. This set-up makes it possible to position the power supply anywhere in the vehicle. Because the whole system is separated into three components (see figure on page 32) – the main unit, the head unit and the power unit – it can be transported easily and installed in the vehicle quickly.

The clutch robot is linked to the user operator laptop by an Ethernet interface and is operated simply via an easy-to-use user interface.

Adjusting the position

The cable pull sensor first detects the current position of the clutch pedal. Based on the current position and the target position, the controller implemented in the RTOS calculates the correcting variable for the linear motor. The implemented controller must be precise and extremely stable throughout the whole application area. Different driver's seats in particular make the setup of the controller more difficult in this regard. In sports cars the seats are generally very firm, while in small cars they are generally softer. In order to take the varying dynamics of driver's seats into account, various components have been added to the PI controller. The controller is therefore completely stable throughout the whole area of application, and there is no need for the user to modify it any further.

Areas of application

Various testing processes can be carried out with the clutch robot. The following three kinds of tests are the most important applications:

- Pedal pressure measurement
- Start-up testing
- Stall testing

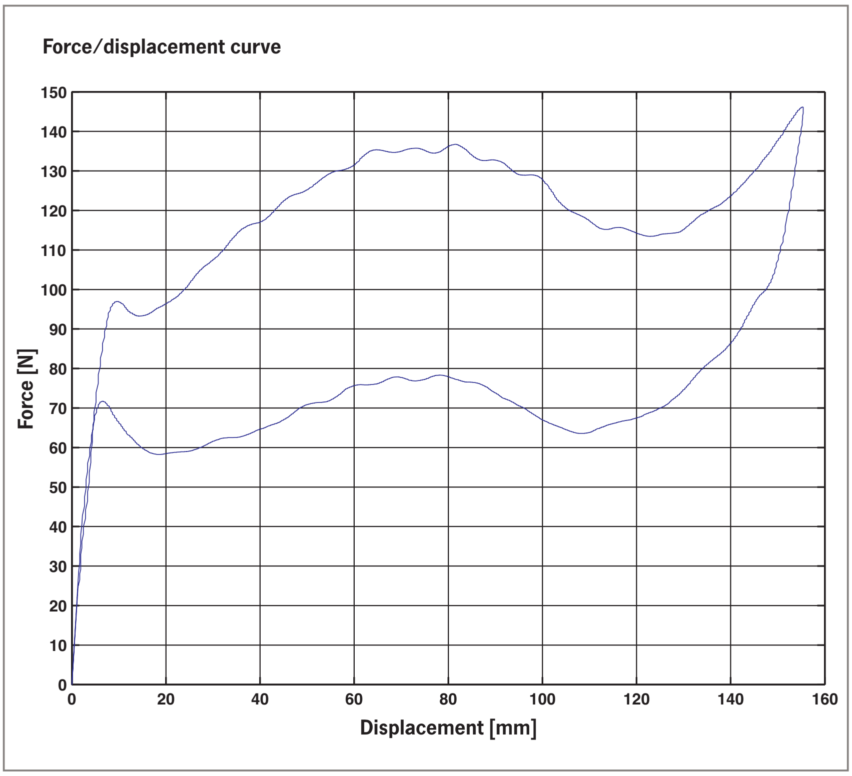
With the aid of powerful analysis software, at the start of testing, the user

Design of the clutch robot:
1. Head unit
2. Connection panel
3. Connection to power supply
4. Main unit
5. Linear motors
6. Coupling bars
7. Load cell
8. Cable pull sensors
9. Power supply

can choose which correcting variables should be saved in a measurement file by the system with up to 1 kHz. The user also has the option to directly connect external temperature sensors to the system. There are also interfaces with the vehicle CAN bus and/or with CAN-based measurement systems. Data collection is carried out by the robotic system itself, and the recorded data can be uploaded to the user PC after the test has been carried out, in order to visually illustrate and evaluate the results. A live readout of the test enables the testing engineer to carry out an initial evaluation of the measurements while the test is still going on.

Pedal pressure measurement

During the pedal pressure measurement test, the pressure placed on the clutch pedal and the pedal travel are recorded. Before the test begins, the combustion engine speed can be set to the desired number of revolutions via the clutch robot. The clutch pedal is then pressed down fully and subsequently brought back to its starting position. The number of test repetitions



Analysis software enables a preliminary assessment during the pedal pressure test

Pedal pressure measurement

as well as the speed of pedal operation can be selected by the user. The result consists of curve graphs depicting pedal pressure in relation to combustion engine speed.

Start-up testing

The aim of the start-up test is to measure the clutch engagement limit speed. What is meant by this is the maximum speed with which the clutch pedal can be operated, and at which starting up the vehicle is still safe.

Before the test starts, the clutch pedal is pressed down completely. Then the user can set the desired combustion engine speed. The accelerator pedal is kept in a constant position by the clutch robot during the entire test. The clutch engagement speed during vehicle start-up is then varied.

The brake pedal can also be set at a desired position in order to prevent the movement of the vehicle before the test begins or to simulate vehicle start-up in relation to braking power. Depending on the set-up of the test, the brakes can be automatically released before the clutch pedal engages at a previously defined, constant speed. After the test has finished, the robot disengages and the accelerator pedal returns to the idle position. Because the tests can be reproduced in different vehicles, objective comparisons can be made between them.

Stall testing

Stall testing is similar to the vehicle start-up test, although here the vehicle is fixed in position with a tow bar. The objective of this test is to establish the drive dynamics and the stability of the engine control unit in relation to the engagement characteristics of the clutch. The tractive power is recorded by the elaborate robotic system. The behavior of the engine is recorded at variable clutch engagement speeds, all the way down to standstill.

Conclusion

With the new clutch robot, the engineers at Porsche Engineering have developed a system that intelligently meets a number of current challenges: the system has an integrated source of power, which can be fed from the vehicle power circuit or can be supplied with electricity by an independent battery pack. This makes it possible to carry out tests on vehicles driving outdoors. Measurement data collection is carried out by the robot itself. The simple setup and removal of the robot does not require the removal of any vehicle components. This enables benchmark testing in several vehicles within a very short period of time. Finally, by utilizing its own sensors and carrying out its own data collection, no additional measurement processes are required – the clutch robot therefore significantly simplifies testing the functions of manually operated clutches in vehicles.

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