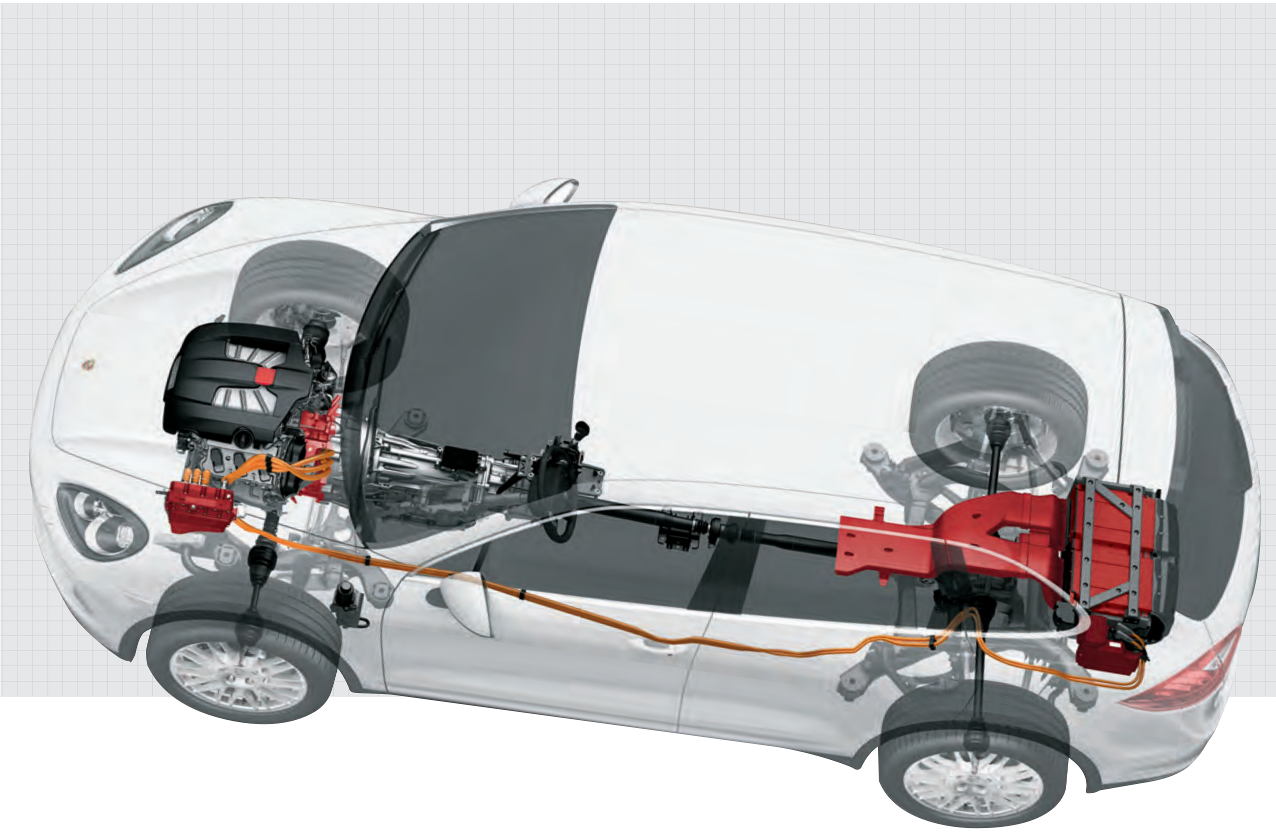

Service Information

2011 Technik Introduction

Cayenne S Hybrid

Important Notice: Some of the contents of this AfterSales Training brochure was originally written by Porsche AG for its rest-of-world English speaking market. The electronic text and graphic files were then imported by Porsche Cars N.A, Inc. and edited for content. Some equipment and technical data listed in this publication may not be applicable for our market. Specifications are subject to change without notice.

We have attempted to render the text within this publication to American English as best as we could. We reserve the right to make changes without notice.

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Foreword

With the launch of the first generation of Cayenne models in 2003, Porsche advanced into the market segment of premium SUVs with great success. The superior performance both on and off the road, the unique design and the exceptional day-to-day usability have impressed so many customers worldwide, that more than 270,000 vehicles from the third series had rolled off the production line by the end of 2009.

New model year 2011 Cayenne models were launched in world-wide markets beginning May, 2010. It was possible to consolidate the leading position of the Cayenne in the areas of driving dynamics and driving performance while keeping CO_2 emissions comparatively low. This could only be achieved by enhancing the drives, making significant reductions in weight using new materials and integrating state-of-the-art technology in our vehicles. A total of five derivatives and three drive types now cover a wider range of customer requirements: In addition to the Cayenne, Cayenne Diesel (not for USA), Cayenne S and Cayenne Turbo models, a modern parallel full hybrid in the form of the Cayenne S Hybrid is now available for the first time.

A high level of qualification throughout the entire AfterSales organization is essential

to meet the high expectations of Porsche customers in spite of the ever increasing complexity of the technology used in the vehicles and the growing number of different variants. This applies in particular to the completely new hybrid technology, which offers enhanced performance while at the same time delivering lower fuel consumption and consequently CO_2 emissions thanks to the interaction between the combustion engine and electric motor. For the 38 kW electric motor, a voltage of 288 V is used in the vehicle, where by specific requirements apply in relation to workshop safety for the repair of vehicles.

This Cayenne S Hybrid Training Information is the training documentation for the 2-day high-voltage technician qualification. It deals not only with differences between the hybrid model and conventional drives, but also with the special features of hybrid technology as well as the specific requirements with respect to high-voltage safety. Following successful completion of this training course, the participant will be a certified high-voltage technician. Only high-voltage technicians are authorized to switch off the electric power in the hybrid vehicle, which is a mandatory requirement for certain vehicle repairs.

Note

The Cayenne S Hybrid Training Information is not intended for use as a basis for performing repairs or diagnosis of technical problems. More detailed information for this purpose is available in PIWIS. We also recommend using the information available in the Porsche Academy.

The content of this brochure corresponds to the information status of February 2010.

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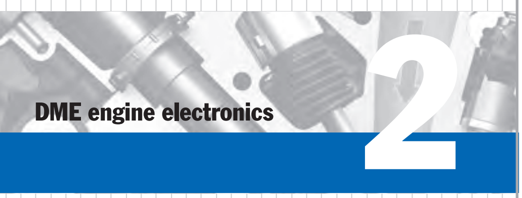

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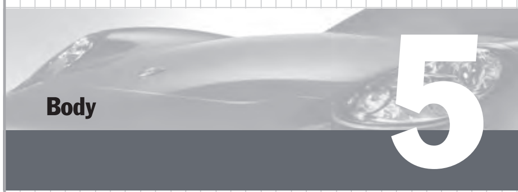

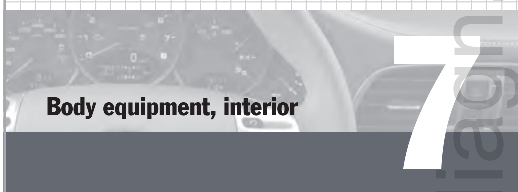


PORSCHE
Cayenne S
S VM 9200

1 Combustion engine

General

An enhanced generation based on the engines familiar from the previous models is used for the new Cayenne models. The Cayenne features the higher-performance 3.6 l V6 naturally aspirated engine, the Cayenne S and Cayenne Turbo the 4.8 l V8 engine. For the new Cayenne S Hybrid with innovative full parallel hybrid drive Porsche is using a 3.0 l V6 unit with supercharging for the first time.

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The new generation of engines offers the following features:

	Cayenne	Cayenne S	Cayenne S Hybrid (combustion engine only),	Cayenne Turbo
No. of cylinders	6	8	6	8
Design	V-engine			
Cylinder angle	15°			
Valves per cylinder	4			
Firing order	1-5-3-6-2-4	1-3-7-2-6-5-4-8	1-4-3-6-2-5	1-3-7-2-6-5-4-8
Injection	Direct fuel injection			
Camshaft control	Intake and exhaust camshafts	VarioCam Plus	Intake camshafts	VarioCam Plus
Displacement [cm³]	3,598	4,806	2,995	4,806
Bore x stroke [mm]	89 x 96.4	96 x 83	84.5 x 89	96 x 83
Compression ratio	11.7:1	12.5:1	10.5:1	10.5:1
Power (DIN) at engine rpm	300 hp/220 kW 6,300	400 hp/294 kW 6,500	333 hp/245 kW 5,500 – 6,500	500 hp/368 kW 6,000
Max. torque at engine rpm	400 Nm 3,000	500 Nm 3,500	440 Nm 3,000 – 5,250	700 Nm 2,250 – 4,500
Turbocharging	-	-	Supercharger	2 turbochargers

Thanks to improved efficiency and the use of the latest engine technology, it was possible to significantly reduce the fuel consumption values for all engines compared with the previous models. It was also possible to reduce CO_2 emissions as a result of reductions in fuel consumption of up to 23 % on certain models. All emission limits are maintained worldwide.

Technical description

The **new 3.0 l V6 supercharged engine with direct fuel injection** installed in the Cayenne S Hybrid guarantees maximum efficiency of the hybrid drive in conjunction with an electric machine. In addition to ensuring typical Porsche driving characteristics with V8 performance, the main development goal was to achieve low fuel consumption, reduced CO_2 emissions and compliance with all worldwide emission standards.

Porsche is using a supercharged V6 engine for the first time. The engine produces **333 hp (245 kW)** at 5,500 rpm to 6,500 rpm and delivers a maximum torque of **440 Nm** in the range between 3,000 rpm and 5,250 rpm.

Cayenne S Hybrid 3,0 TFSI Engine data

Cylinder spacing	90 mm
Cylinder bank offset	18.5 mm
Main bearing diameter	65 mm
Con-rod bearing diameter	56 mm
Con-rod length	153 mm
Block height	228 mm
Displacement	2995 cm^3
Stroke	89 mm
Bore	84.5 mm
Compression ratio	10.5:1
Max. power at engine rpm	333 hp (245 kW) at 5,500 to 6,500 rpm
Max. torque at engine rpm	440 Nm 3,000 to 5,250 rpm

Characteristics

The most important characteristics of the new 3.0 l V6 supercharged engine include:

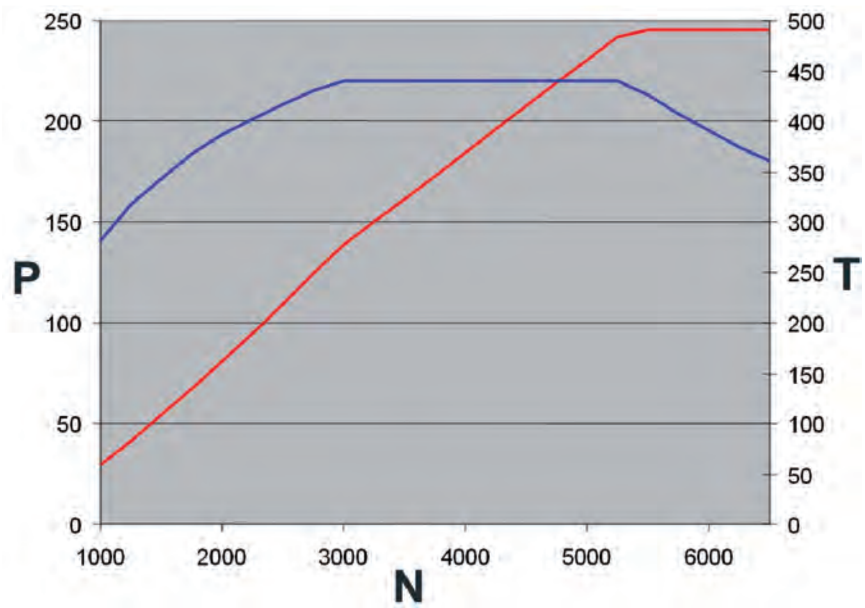
- Cylinder bank angle 90°
- Wet-sump lubrication
- Supercharger
- Charge-air cooling
- Fuel consumption measures on intake side
- Aluminum cylinder head
- Solid aluminum engine block
- Four-valve technology
- Continuous camshaft adjustment

The engine is a 6-cylinder, 24-valve gasoline engine with a cylinder bank angle of 90 degrees and two camshafts per cylinder bank. The 3.0 l V6 engine consists of an aluminum engine block, an aluminum cylinder head and other state-of-the-art technological features such as thermal management and a regulated oil pump.

The oil supply system is based on the principle of wet-sump lubrication, which safeguards the functions of the engine in dynamic driving mode and on slopes or steep uphill climbs when driving off-road, for example. In contrast to previous turbocharged engines used in Porsche models, turbocharging on the new unit is achieved using a supercharger with charge-air cooling. The supercharger with charge-air cooling offers special advantages for the specialized use and characteristics of the full parallel hybrid drive in an SUV. Because the supercharger has a permanent mechanical connection with the crankshaft drive, the boost pressure is available immediately and the mass air flow through it increases continuously together with the speed of the combustion engine. The supercharger is located directly inside the inner V of the engine, which means that the aspirated, compressed air does not have far to travel to the cylinders and consequently the engine offers outstanding response characteristics. The enhanced response of the engine reaps particular benefits at low speeds in an urban driving environment, where the Cayenne S Hybrid is able to demonstrate the positive effect that the Auto Start Stop function, the recovery of brake energy and driving solely under electric power have on fuel consumption. The exhaust gas after-treatment system also benefits because the catalytic converter reaches the perfect operating temperature more quickly.

The supercharger in the Cayenne S Hybrid is a space-saving **Roots blower** with charge-air cooling and a bypass valve that guarantee the rapid response of the V-engine. Two parallel shafts in the supercharger housing connected via a gear stage are powered by a separate belt drive. The gear stage enables the fully synchronous rotation of the two shafts in opposite directions to one another. Rotors are mounted on both shafts and are sealed on all sides (opposite the blades on the second shaft and the supercharger housing). The two shafts rotating in opposite directions convey the uncompressed air mass from the air inlet, between the rotors into the supercharger and then to the air outlet. (Each rotor is fitted with 4 vanes and positioned at 160 degrees to the longitudinal axis to guarantee a continuous flow of air.) Compression occurs when the mass of air that has accumulated in front of the intake valves is forced inwards. The supercharger is fitted with a **charge-air cooler** for each cylinder bank with a low-temperature coolant system to enhance the turbocharging effect.

The supercharger is equipped with an integral **boost-pressure control** because charge air is not required in all operating modes and the continuous increase in boost pressure would result in an excessive accumulation of air and therefore a loss in power. A bypass valve is used instead of a complex boost pressure control that incorporates a magnetic clutch for engaging and disengaging the supercharger. Once the specified or maximum boost pressure is reached, some of the delivered air can be returned back to the intake side by opening the bypass valve.



P Power output in kW
N Engine speed in rpm
T Torque in Nm

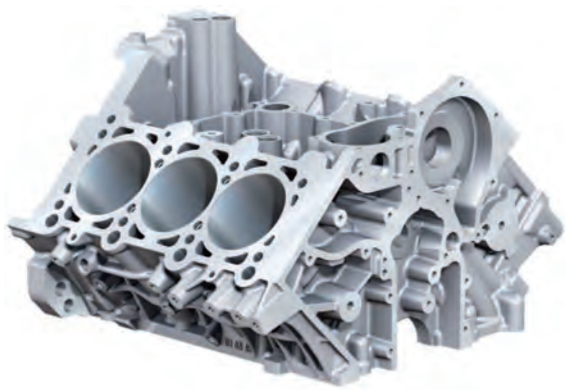
Power curve
Torque curve

Crank drive

Cylinder block

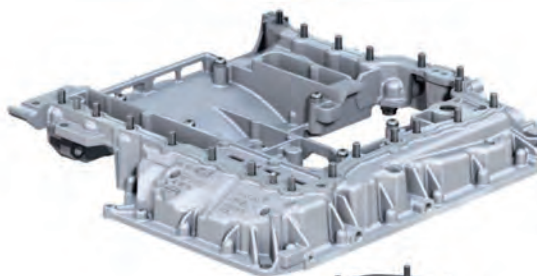
The cylinder block undergoes special heat treatment during the manufacturing process to withstand the load generated by the combustion pressure in the area around the bearing blocks. The strength class of the main bearing bolts is also high.

Cylinder block



Bottom section of crankcase (bed plate)

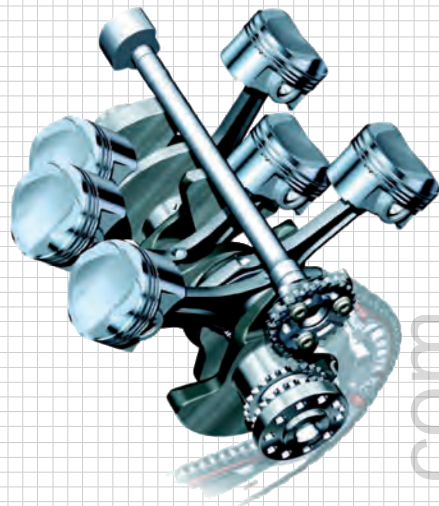
Upper part of oil pan



Lower part of oil pan

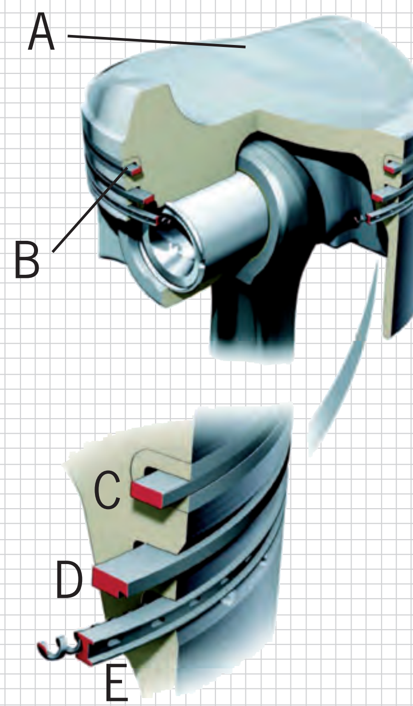
Crankshaft

The crankshaft was constructed for a stroke of 89 mm and has a split-pin design. The fractured connecting rods are 153 mm long and have a reinforced design. All bearing shells are lead-free and have a three-material design.

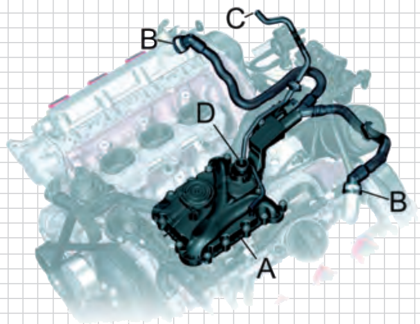


Pistons

The pistons are ring carrier pistons designed for a compression ratio of 10.5 : 1. The piston shanks also have a wear-free Ferrostan coating. At high power levels, a correct combination of ring pistons will ensure low blow-by gas flow and oil consumption values while simultaneously minimizing friction and wear.

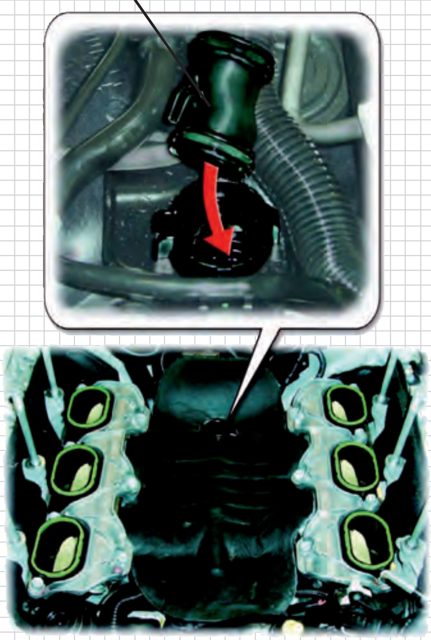


A Cast piston
B Ring carrier
C 1.2 mm asymmetrically convex steel ring
D 1.5 mm stepped taper-faced ring
E 2.0 mm two-piece oil scraper ring



A Oil separator module
B Cylinder head cover connection (with integral labyrinth oil separator)
C PVC line with check valve
D Connection to air-charging module

Intermediate piece



Crankcase ventilation

A head vent with valves covers that dissipate the blow-by gases is used to ventilate the positive crankcase. A labyrinth for coarse separation is integrated in the valve covers. The gas flows through flexible plastic lines to the inner V on the engine block, where the oil separator module is located. The coolant ducts are integrated into the oil separator module. The oil separator module doubles up as a cover that closes off the engine block. The gases are purified in two cyclones that operate in parallel. If the gas flow is too high, a bypass valve opens to prevent the pressure inside the crankcase from exceeding permitted levels. After purification, the gases flow directly into the air-charging module through the air-charging module connection.

The oil accumulates in a collection chamber in the lower part of the oil separator. An oil drain valve closes off the collection chamber while the engine is running. The pressure inside the crankcase forces the oil drain valve against the sealing face. The collection chamber is large enough to collect all the oil generated during the time the engine takes to consume a full tank of fuel. Another drain valve for draining condensed fuel vapours or water is located in the area below the pressure-regulating valve.

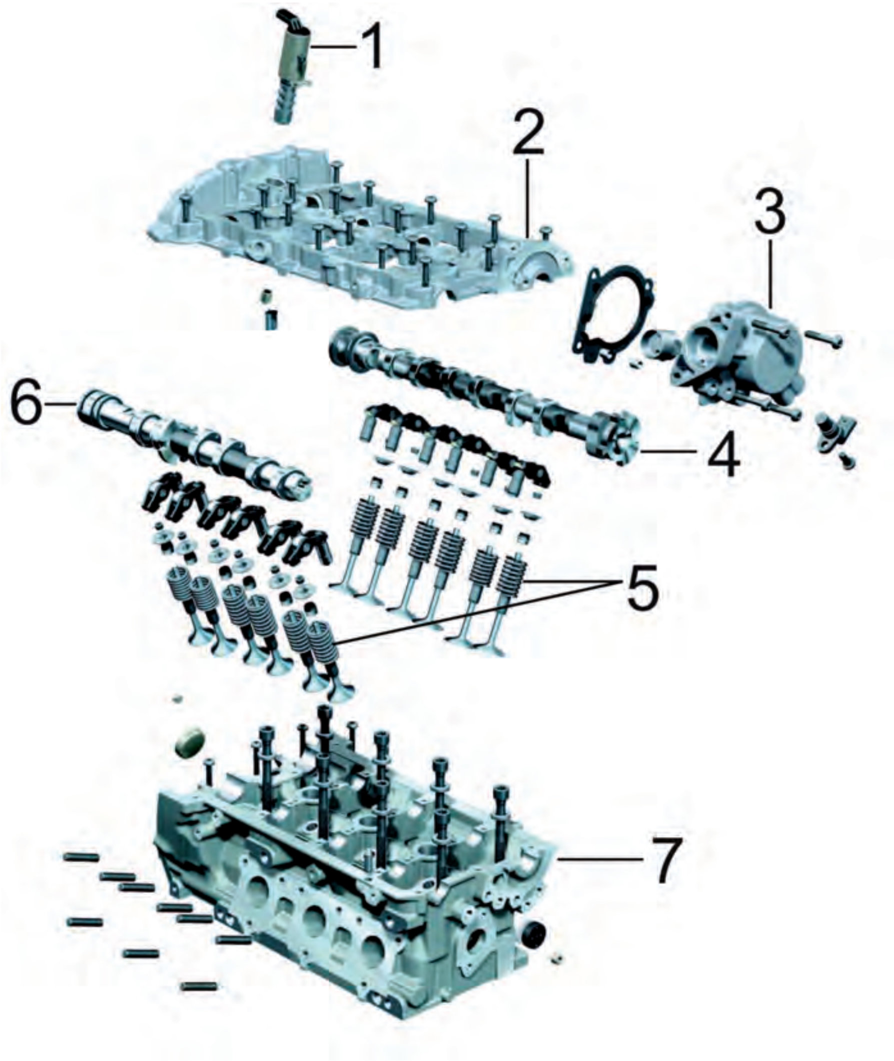
Connection to the air-charging module

Blow-by gases are directed into the air-charging module from underneath. An intermediate piece seals the feed line against the air-charging module. The opening on the air-charging module is conical in shape to allow for easier insertion of the intermediate piece. When the intermediate piece is fitted, a lug secures the component in the correct position at the positive crankcase ventilation output.

Cylinder head

Valve lift adjustment and the adjustment of the outlet camshafts are omitted from the 3.0 DFI engine because a supercharger is installed.

A detailed illustration of the cylinder head components:

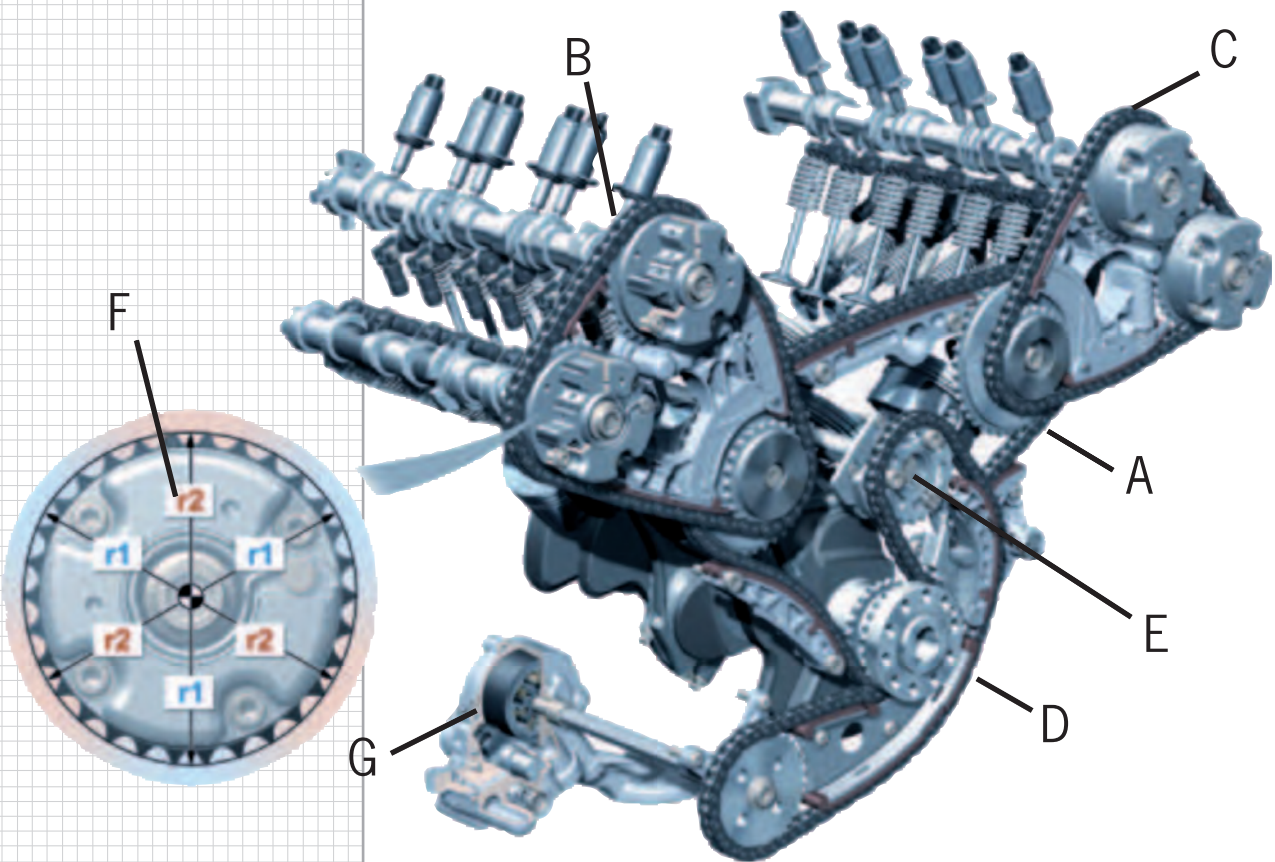


1 Valve for intake camshaft control
2 Cylinder head cover
3 High-pressure fuel pump
4 Intake camshaft
5 Valves with valve springs and rocker arms
6 Exhaust camshaft
7 Cylinder head housing

Chain drive

Timing drive mechanism with trioval sprockets

Torque must be applied to open the valves on a cylinder. On a V6 engine, the valve on each cylinder bank and camshaft opens three times during every working cycle. As a result, higher forces act on the chain drive every time the valve opens. These forces may cause vibrations in the timing drive mechanism that can be felt at higher speeds in particular.



A B C Roller-type chain **D** Bush chain **E** Balance-shaft drive
F Trioval sprocket **G** Vane oil pump

Technical characteristics of the trioval chain drive

Trioval sprockets are used to drive the camshafts on the Cayenne S Hybrid engine.

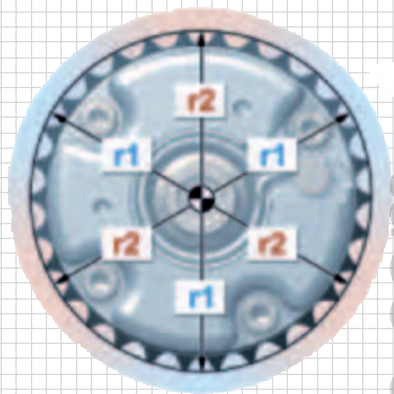
Function:

The trioval sprockets are raised in three places and are therefore not perfectly circular. The elevations increase the outer diameter of the sprocket as well as the effect of the lever arm that acts on the valves. When a cam needs to open the valve, the elevations (larger arm) act at exactly the right moment. The extension of the lever arm leads to a reduction in the chain forces and dampens disruptive vibrations.

Advantages:

The lower chain forces reduce friction and also fuel consumption. Furthermore, more cost-effective chains and chain tensioners with identical performance characteristics can be used. A further advantage is the reduction in vibrations, which allows the chains to run more smoothly.

r1 > r2

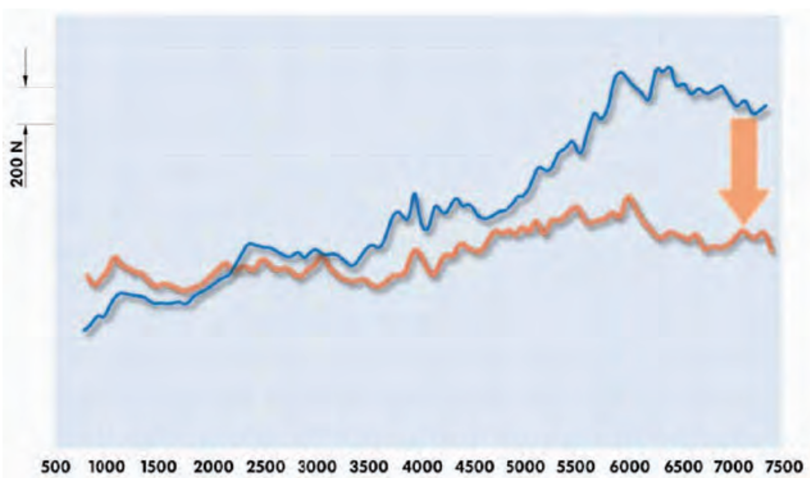


Trioval sprocket

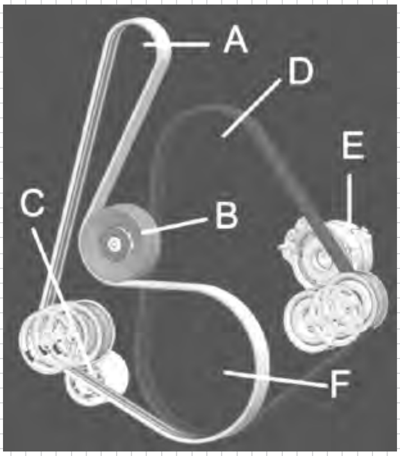
Tip circle diameter in mm

r1 = 46.86

r2 = 45.71



Reduction of chain forces from trioval sprockets throughout the entire speed range approx. 35%. without trioval sprockets with



A Supercharger
B Deflection roller
C Belt drive tensioning device A
D Coolant pump
E Belt drive tensioning device B
F Crankshaft

Auxiliary system drive

The engine is fitted with two separate belt drives that power the auxiliary units. Because various auxiliary systems on the Cayenne S Hybrid are powered electrically (air-conditioning compressor, power steering, etc.) and the generator has been replaced with the E-machine, the tensioning force on the two drive belts can be reduced. Belt drive A powers the drive belt for the supercharger via the crankshaft drive sprocket and belt drive B powers the coolant pump.

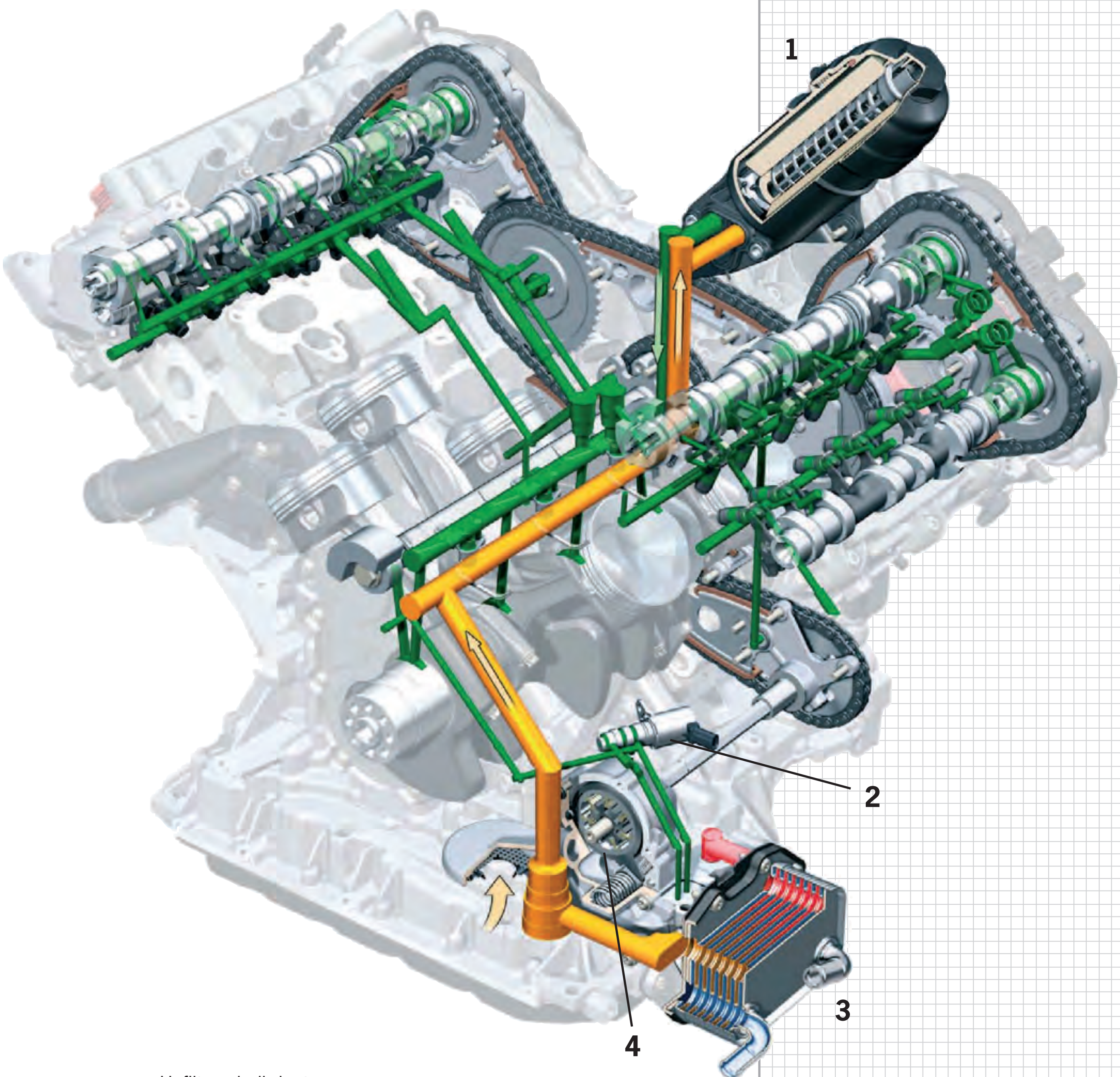
Oil supply system

When the lubrication system was developed, the most important objective was to reduce friction inside the engine even further. A series of measures such as the modified chain drive were implemented. In addition, improvements in the oil circuit have significantly reduced the oil flow rate.

Improvement measures:

- Modification of the sickle groove on the main bearing shell of the crankshaft from 180° to 150°
- Relocation of the oil feed bore in the camshaft bearings
- Halving of the flow rate through the piston spray nozzles
- Reduction in leaks from the camshaft controller incl. valves for camshaft control
- The oil supply system for the continuous camshaft controller has been decoupled from the cylinder head oil supply system (camshaft bearings and hydro elements). It was therefore possible to restrict the oil pressure in the cylinder head while simultaneously improving the connection between the cam - shaft control valves and the oil supply system.

Design of the oil supply system



Unfiltered oil duct

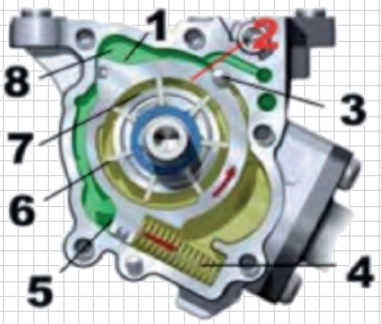
Filtered oil duct

1. Oil filter module
2. Oil pressure regulator
3. Oil cooler
4. Self-regulating oil pump

Volume rate controlled oil pump

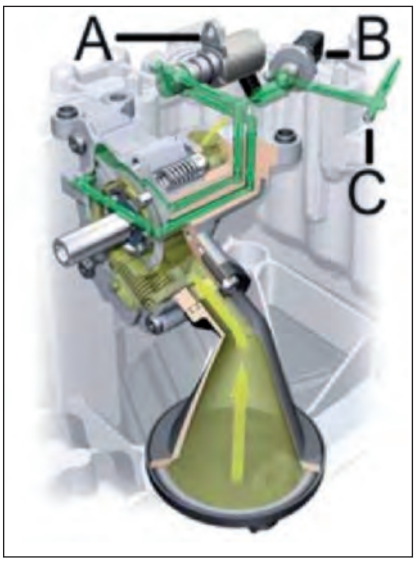
Low delivery rate

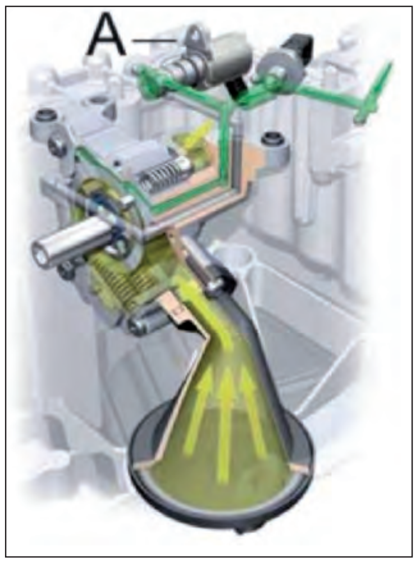
One measure to reduce the required drive power of the oil pump is the use of a flow rate control. As a result, a vane pump whose delivery characteristics can be changed using a rotatable adjusting ring is installed in the engine of the Cayenne S Hybrid. This adjusting ring can be loaded with oil pressure via the control surfaces 1 + 5 and pivoted against the force of the control spring. In the lower rpm range, the engine control unit connects the energized control valve to ground and opens the oil duct to the second control surface of the adjusting ring. Both oil flows then act on both control surfaces with the same pressure. The resultant forces are greater than the force of the control spring and pivot the adjusting ring in an counter-clockwise direction. The adjusting ring swivels into the center of the vane pump and reduces the delivery space between the pump cells. The lower pressure level is switched depending on the engine load, engine speed, oil temperature and other operating parameters, thereby reducing the drive power of the oil pump.



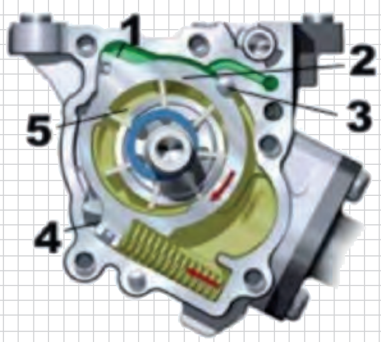
Vane pump, low delivery rate

1	Control surface 1	5	Control surface 2
2	Adjusting ring	6	Cells
3	Support	7	Delivery chamber
4	Control spring	8	Oil pressure from the oil duct of the crankshaft





A Control valve
B Oil pressure switch
C Oil duct of the crankshaft
Control valve **activated - low** delivery rate
Control valve **deactivated - high** delivery rate

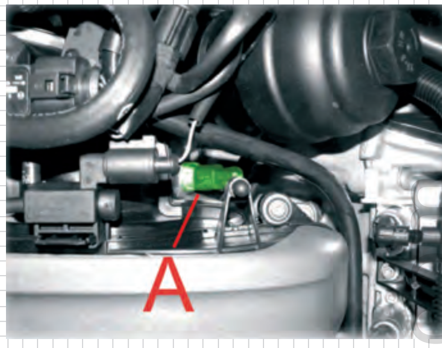


Vane pump, high delivery rate

1 Control surface 1
2 Adjusting ring, max. delivery rate
3 Support
4 Control surface 2
5 Delivery chamber

High delivery rate

As from an engine speed of 2,500 rpm or a torque of 300 Nm (full-throttle acceleration), the engine control unit isolates the solenoid valve from the ground connection so that the oil duct to control surface 2 is closed. The oil pressure present then acts only on control surface 1 and opposes the force of the control spring with a lower force. The control spring then pivots the adjusting ring around the support in a clockwise direction. The adjusting ring now swivels out of the centre position and increases the delivery space between the individual cells. A greater quantity of oil is delivered due to the larger spaces between the cells. The higher oil flow quantity is opposed by resistance from the oil bores and the bearing clearance of the crankshaft, which allows the oil pressure to increase. Realisation of a volume flow-controlled oil pump with two pressure stages was therefore possible.



A Oil pressure switch for reduced oil pressure

Oil pressure monitoring

Two oil pressure switches are responsible for monitoring the oil pressure. Two switches are required to monitor the pressure in order to control changes to a high or a low oil pressure. The switches are not integrated in the instrument cluster.
The engine control unit evaluates the signals from the oil pressure switches. If it becomes necessary to illuminate the warning lamp in the instrument cluster, a message is sent to the CAN data bus and the warning lamp in the instrument cluster is activated.

Oil pressure switch for reduced oil pressure

The switch for reducing the oil pressure closes when the oil pressure reaches 13 psi (0.9 bar). If the oil pressure falls below this range, the switch opens and the engine control module activates the warning lamp in the instrument cluster via the CAN bus. The oil pressure switch is installed in the main oil duct upstream of the oil filter module.

A Installation location of the oil pressure switch

Oil pressure switch

The oil pressure switch operates within a pressure range that is higher than the switching threshold of the oil pressure control valve. The switch closes at an oil pressure of 36 psi (2.5 bar). The signal that the engine control module receives from the oil pressure switch indicates that the oil pump is generating the required oil pressure. The oil pressure switch is installed in the pressure oil duct downstream of the oil filter in the oil filter module.

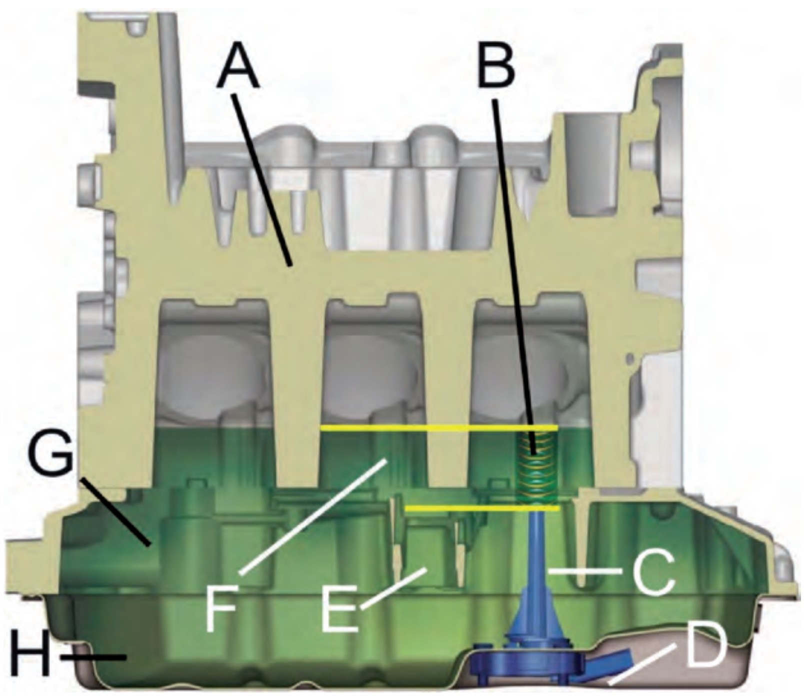
Oil level indicator

The engine on the Cayenne S Hybrid is equipped with an oil level sensor that operates according to the ultrasonic measuring principle (PULS = Packaged Ultrasonic Level Sensor) to display the oil level in the instrument cluster.

Operating principle

The transmitted ultrasonic impulses are reflected by the oil/air boundary layer. The oil level is calculated from the time difference between the transmitted impulse and the return impulse, taking into account the speed of the sonic signal.

Sensor electronics integrated in the oil level sensor housing process the measured signal and then output a PWM signal (PWM = pulse width modulation).



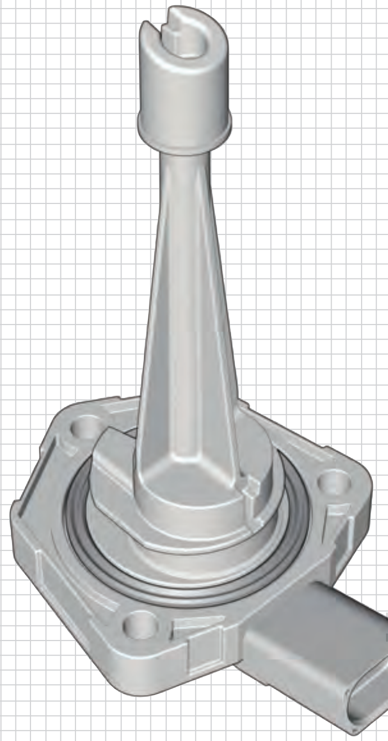
A Engine housing
B Virtual cylinder (20 mm Ø)
C Oil level sensor
D System zero point
E Dynamic measuring range (15 to 75 mm)
E Static measuring range (75 to 120 mm)
G Upper oil pan
H Lower oil pan

Advantages of the ultrasonic sensor:

• Sensor signal available almost immediately (after approx. 100 ms)
• Low current consumption < 0.5 A

The signal from the oil level sensor is evaluated in the engine control unit, which then transmits the calculated values to the CAN Drive. The diagnostic interface for the data bus (Gateway) forwards the signals to the corresponding bus systems.

The indicator used in the Cayenne S Hybrid displays a realistically calculated oil level. The oil dipstick is therefore omitted. The customer still has the option of checking the oil level via the indicator on the instrument cluster. The pipe that usually holds the oil dipstick is still installed in the vehicle as it can be used in the workshop to extract oil from the engine. The end of the pipe is closed off with a plug.



Calculating the oil level

Two methods are used to calculate the oil level: dynamic and static measurement. **Dynamic measurement** takes place while the vehicle is driving. Key measurement factors here are:

- Engine speed
- Axial and lateral acceleration from the PSM control unit
- Engine cover contact (bonnet must be closed)
- Engine temperature (engine must be at operating temperature)
- Driving cycle since the engine cover was last opened > 30 miles (50 km)
- A certain number of values must have been measured during the driving cycle

The dynamic measurement method is more accurate and is used most of the time. However, there are some instances where dynamic measurement cannot be used. Measurement is **interrupted** if:

- Acceleration values exceed 3 m/s^2,
- Oil temperature exceeds 284° F. (140° C.) and
- Contact switch for the engine cover is actuated.

Static measurement is used where dynamic measurement is not possible such as the instances mentioned above. Static measurement is used if the:

- Ignition is "on“. The measuring process is initiated as soon as the driver's door is opened in order to obtain a measured result as quickly as possible.
- Engine oil temperature > 104° F. (40° C.),
- Engine speed < 100 rpm and
- Engine is off > 60 sec.

The acceleration values from the PSM control unit are also included here in case the vehicle is parked on an incline. The signal from the parking brake is also used. A low level warning is issued if the oil reaches a level where the engine could become damaged (value below minimum level). A high level warning is issued if the oil reaches a level where the engine could become damaged (value above maximum level).

Example of when static measurement is required

The vehicle is refuelled at a service station and the bonnet is opened to refill the washer fluid. Dynamic measurement is interrupted when the contact switch for the engine cover is actuated. The signal from the oil level sensor is read via CAN. In this instance, the oil level would only be displayed again after a driving cycle of 30 miles (50 km). The customer would not be able to check the oil level at the service station as a result. Mechanics must also be able to check the oil level via the indicator when the vehicle is parked in the workshop.

Cooling system

In addition to the significant weight reduction in all Cayenne models, mainly in the body and chassis, numerous detail features and the use of the state-of-the-art engine technology have contributed to reducing fuel consumption values. The thermal management system has made an important contribution to achieving these objectives.

More detailed information on thermal management can be found in the chapter describing the Cayenne S Hybrid engine, but only regarding the cooling system and the different warm-up phases. Information on activation of the electrically powered pumps and integral thermostats is described in the chapter "Engine control".

Thermal management

All Cayenne engines meet the high demands placed on a Porsche engine under all operating conditions and therefore also meet the special requirements that apply to warm countries. The Cayenne S Hybrid is designed to meet all performance requirements whether on-road, off-road or in traction mode. The cooling system ensures that the engine runs at a favorable operating temperature for optimum and permanent high performance. Further advantages are provided by the low fuel consumption and emission values, since all components reach the optimum operating temperature quickly. A new thermal management system is used for the engine, the Tiptronic S transmission and hybrid components (E-machine and power electronics) on the Cayenne S.

Warm-up strategy of the thermal management system on the Cayenne S Hybrid

Goal

- Rapid heating of friction-relevant fluids such as oils, implemented by way of static coolant, for example
- Heat management (focus on consumption and comfort, etc.)
- Decoupling of masses with sluggish thermal response in the system
- Enhanced heating comfort

Warming-up process

- Engine warm-up
- Heating of passenger compartment as required, transmission prevented from heating up
- Transmission heating
- Heat dissipated via main cooler

Other requirements

- Hybrid: Cooling requirements of the E-machine and power electronics are fulfilled at all times

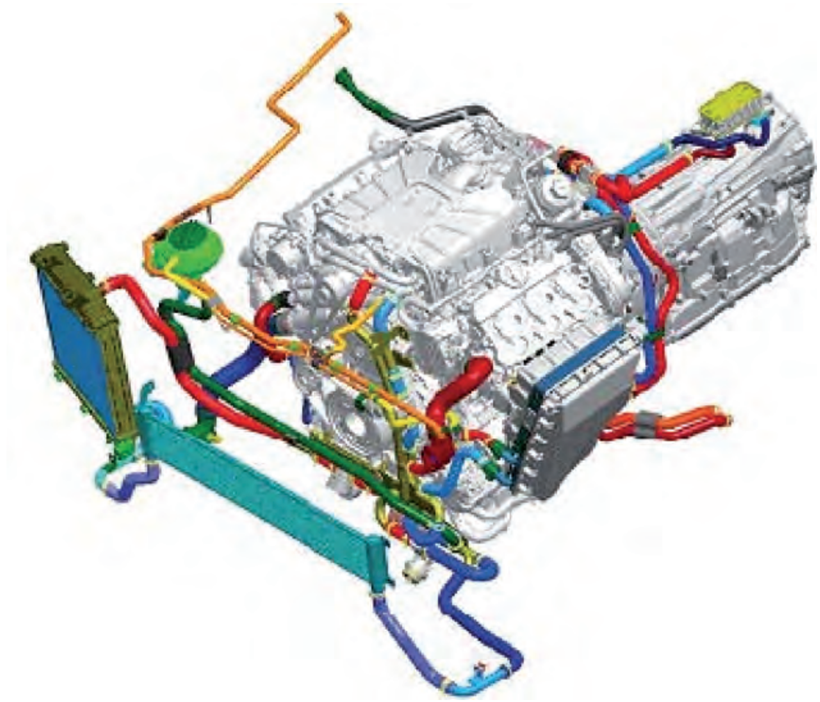
The main areas of the **thermal management system** in the Cayenne S Hybrid are heat distribution between the **combustion engine, transmission** and **passenger compartment** (high-temperature cooling system). In addition to the high-temperature cooling system, a low-temperature cooling system is installed to cool the charge-air cooler and the hybrid power electronics.

! Please read the work instructions in the Workshop Manual before filling or bleeding the cooling system.

The basic goal is to ensure that all components reach their optimum operating temperature as quickly as possible and to also meet the comfort demands of passengers by heating up the cabin quickly. At low temperatures and for cold engine starts in particular, it is important to manage the low amount of available heat in the best possible way. Efficient use of the available heat helps to save fuel, reduce CO_2 emissions and comply with strict emission regulations.

High-temperature cooling system

The cooling system is part of the thermal management system and has two circuits which can be controlled depending on the coolant temperature via a thermostat. The thermostat permits automatic, demand-based suppression of the coolant flow when the engine is cold (cold start). As a result, the engine heats up more quickly and prevents friction more effectively, which presents the advantages mentioned previously. Depending on the increase in engine temperature, the coolant flow through the engine (small circuit) is then activated during warming up. After this, the large circuit is activated depending on the engine operating point and based on a map stored in the engine control. The thermostat control then regulates the coolant temperature depending on the load to ensure that the temperature conditions in the engine are adapted perfectly for the respective load point.



Overview of complete system including high-temperature and low-temperature circuits

This thermal management system made it possible to reduce fuel consumption by accelerating the warm-up phase after a cold start. Furthermore, the Cayenne S Hybrid is also equipped with thermal management for the transmission, as already mentioned. Here also, the aim is to reach the optimum operating temperature as quickly as possible in order to minimize friction losses. For this purpose, the heat exchanger of the cooling system for the new 8-speed Tiptronic S is connected to the engine cooling system. If necessary, this allows the heat of the engine coolant, which is heated up more quickly, to be used to bring the transmission up to its operating temperature.

Function of thermal management:

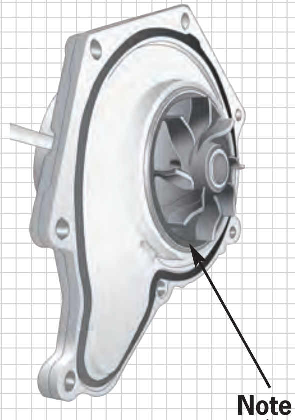
When the case on the main water pump is closed, the water remains in the cylinder head and crankcase to heat the engine more quickly (stationary water). When the heating shut-off valve is opened and the auxiliary water pump is connected automatically, warm water is supplied to the heating system.

Effect of thermal management:

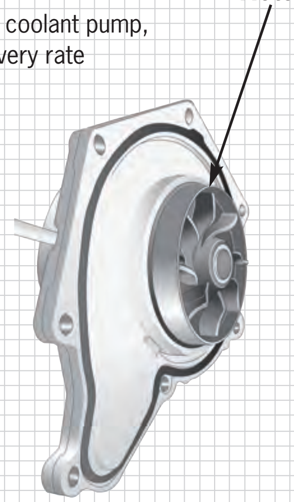
- Reduced cooling power during the engine operation phase
- This results in faster heating of the transmission and engine oil
- Less internal friction in the engine and transmission components

The result:

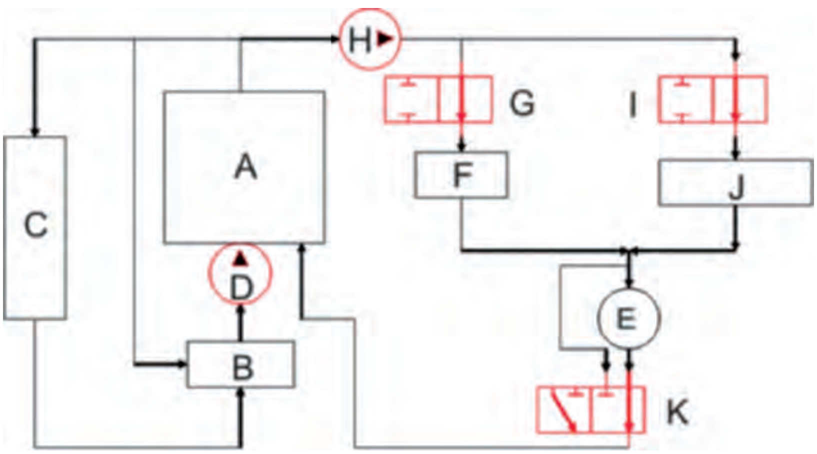
- Reduced fuel consumption
- Faster heating of the passenger compartment (with priority over engine oil heating)
- Increase in fuel economy of up to approx. 1.5 %



Encased coolant pump,
high delivery rate

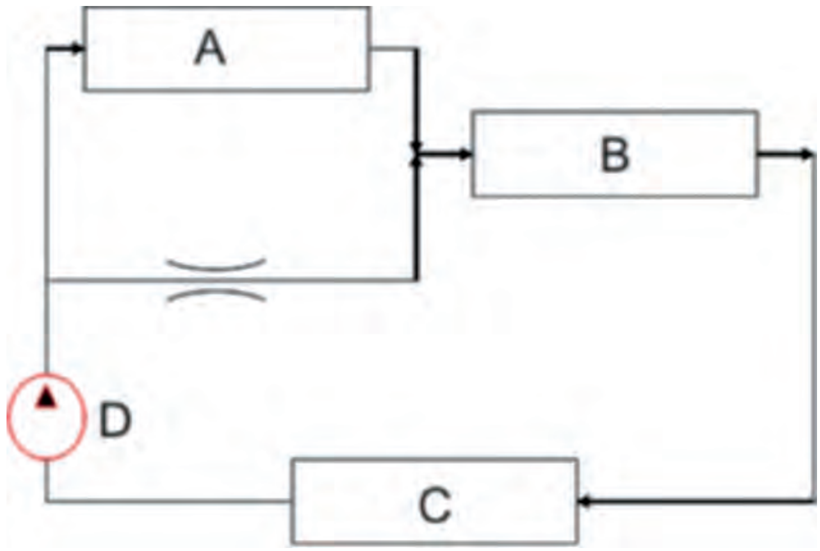


Encased coolant pump,
low delivery rate



High-temperature cooling system

A Engine
B Thermostat
C High-temperature cooler
D Encased main water pump
E E-machine
F Transmission oil cooler
G Transmission shut-off valve
H Auxiliary water pump
I Heating shut-off valve
J Heat exchanger
K E-machine bypass valve



Low-temperature cooling system

A Power electronics

B Charge-air cooler

C Low-temperature cooler (max. 140° F. (60° C.)

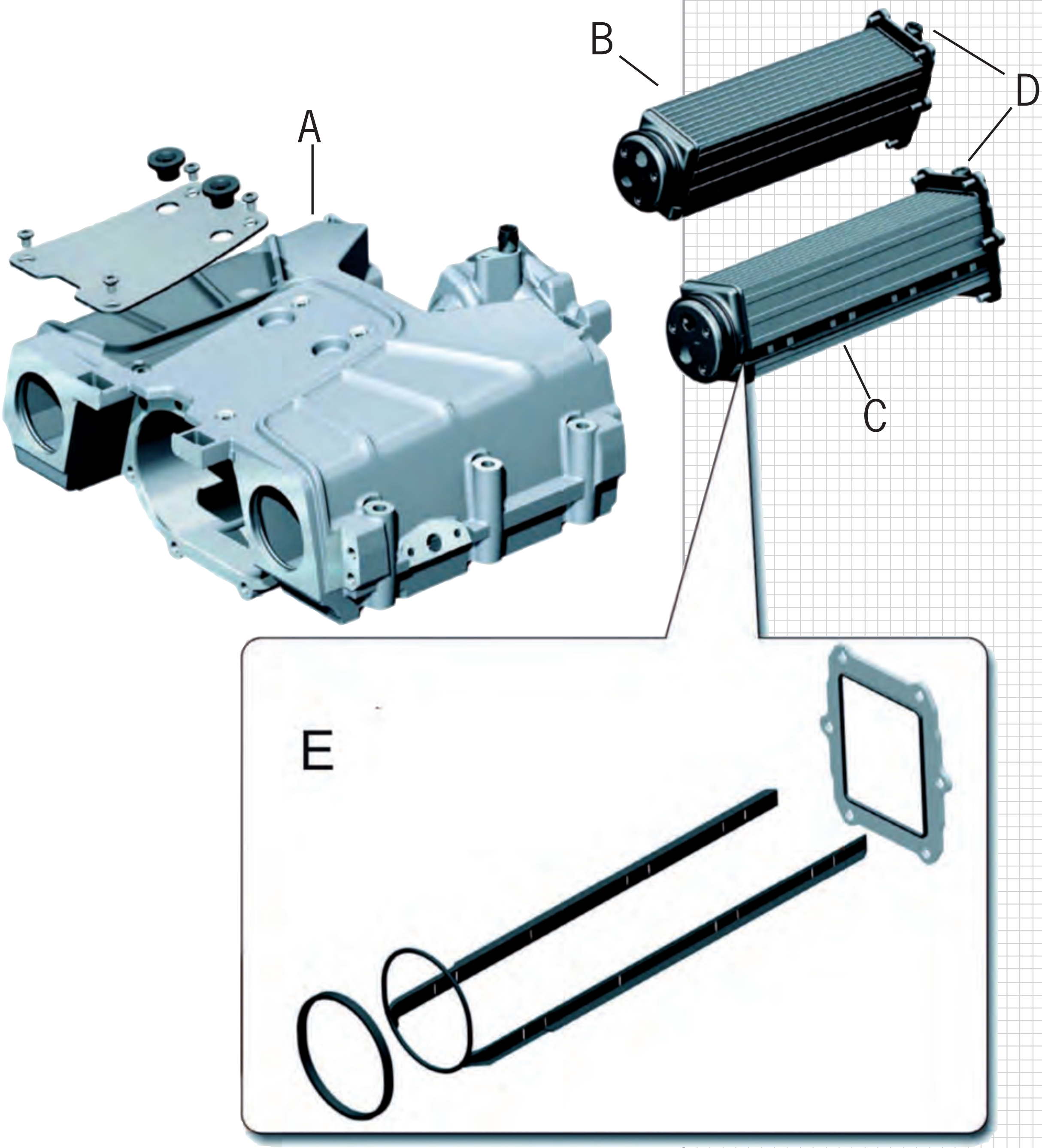
D Auxiliary water pump

The cooling system is part of the thermal management system and has two circuits which can be regulated depending on the coolant temperature. An electric, map controlled thermostat that can be deactivated is used to regulate the circuits on the Cayenne S Hybrid. Depending on the increase in engine temperature, the coolant flow through the engine (small circuit) is then activated during the warming-up phase.

After this, the coolant radiator is activated (large circuit) depending on the engine operating point and based on a map stored in the engine control. The map control of the thermostat then regulates the coolant temperature between 201° F. (94° C.) and 221° F. (105° C.) depending on the load and therefore adapts the friction conditions in the engine perfectly to the respective load point.

Charge-air cooling

One charge-air intercooler for each cylinder bank is installed in the air-charging module. Coolant flows through the coolers, which are integrated in parallel in the charge-air cooling system.



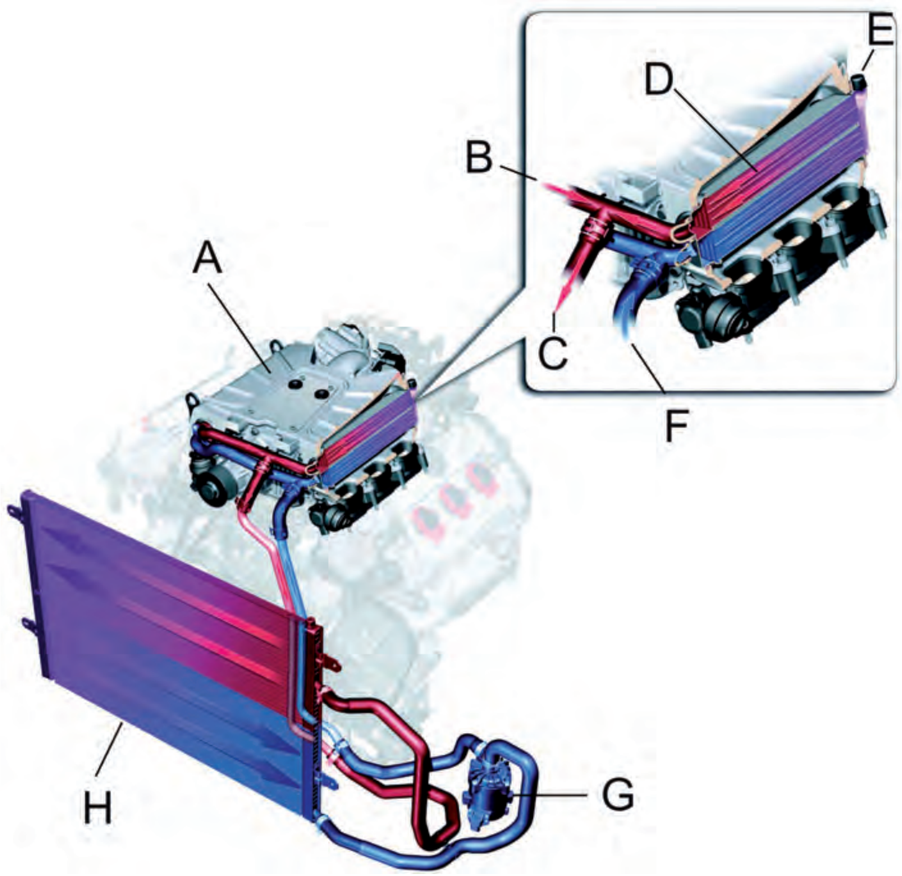
A Air-charging module B - Charge-air intercooler, right
C Charge-air intercooler, left D - Bleeder screws
E Gasket set for charge-air intercooler

!

The charge-air cooler must be installed and removed with great care. Read the instructions in the Workshop Manual.

Charge-air cooling system

The charge-air cooling system is an independent high-temperature cooling system that also cools the hybrid power electronics. The system operates independently of the main cooling system, although the two systems are connected to one another and both utilize the coolant expansion tank. The temperature levels in the charge-air cooling system are lower than those in the main system.



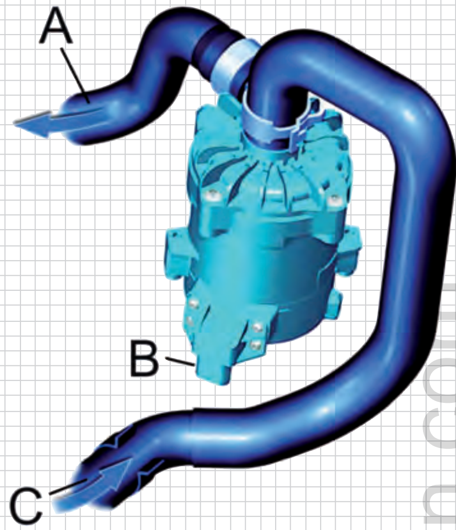
A Air-charging module
B Coolant return line from charge-air intercooler, right
C Coolant return line
D Charge-air intercooler, left
E Bleeder screw
F Coolant supply line
G Pump for charge-air cooling
H Charge-air cooler

Pump for charge-air cooling (G)

The charge-air cooling pump is an electrically powered coolant pump. The pump conveys the heated coolant from the charge-air intercoolers in the air-charging module to the low-temperature cooler. This cooler is installed in the cooling module in the vehicle engine compartment (in front of the main cooler viewed in the directi-on of travel). The pump is installed at the front left of the engine compartment near the oil cooler. The pump is designed based on a centrifugal pump.

A centrifugal pump is not self-aspirating and should therefore not be allowed to run dry because the pump bearings may overheat. The following assemblies are integrated in the pump module:

- Centrifugal pump
- Electric motor
- Electronic control



A Pressure connection
B Electrical connection
C Intake connection

Function of the pump control

The pump is activated depending on the temperature from a map in the engine control module downstream of the charge-air cooler and the pressure downstream of the charge-air cooler. It always runs from 1,300 mbar or from a coolant temperature of 122° F. (50° C). The pump is controlled by the engine control unit via a PWM signal. The pump electronics use this signal to calculate the required pump speed and control the electric motor. If the pump is working correctly, the pump electronics send the current pump speed back to the engine control module. This process runs cyclically throughout pump operation.

Effects in the event of faults

If the pump electronics detect an error, the PWM signal changes. The changed signal is evaluated by the engine control unit. The actual response depends on the nature of the fault. If a fault is detected, fault entries are made in the memory of the engine control unit. In the event of a failure, no indicator lights are activated because a reduction in power is only noticeable at full throttle and the exhaust gases are not affected. No direct replacement reaction is triggered in the engine control unit in the event of pump failure. However, the charge air temperature is monitored. If this is found to be too high, the engine control unit reduces the engine power. If the signal line to the pump is interrupted or there is a short circuit to positive on the signal line, the pump switches to emergency mode, in which it delivers 100% output. The pump stops in the event of a short circuit to ground on the signal line.

Fault detection

Attempts are made to protect the pump whenever a fault is detected. Either the pump speed is reduced or the pump is switched off. The following table contains a list of possible faults and potential consequences:

Fault type	Effect
Insufficient coolant resulting in dry operation (pump speed excessive)	Speed reduction to 80 % (maximum 15 rpm)
Low coolant level > 15 min	Pump is switched off
Overtemperature	Speed reduced in two stages to 80 % and 50 %
Undertemperature (cold/viscous coolant increases current consumption)	Speed reduced in two stages to 80 % and 50 %
Overvoltage	At voltages > 20 V, the pump switches off until the voltage returns to permitted levels
Impeller seizes	Pump is switched off. Multiple activation in an attempt to "shake free" the impeller
Temperature of the pump electronics > 320° F. (160 ° C.)	Pump switches off until the temperature decreases sufficiently

Diagnosis options with the PIWIS Tester, second generation

The following diagnostic options are available:

- Read out the fault memory in the engine control unit
- Guided Fault Finding
- Read out actual values
- Drive link test

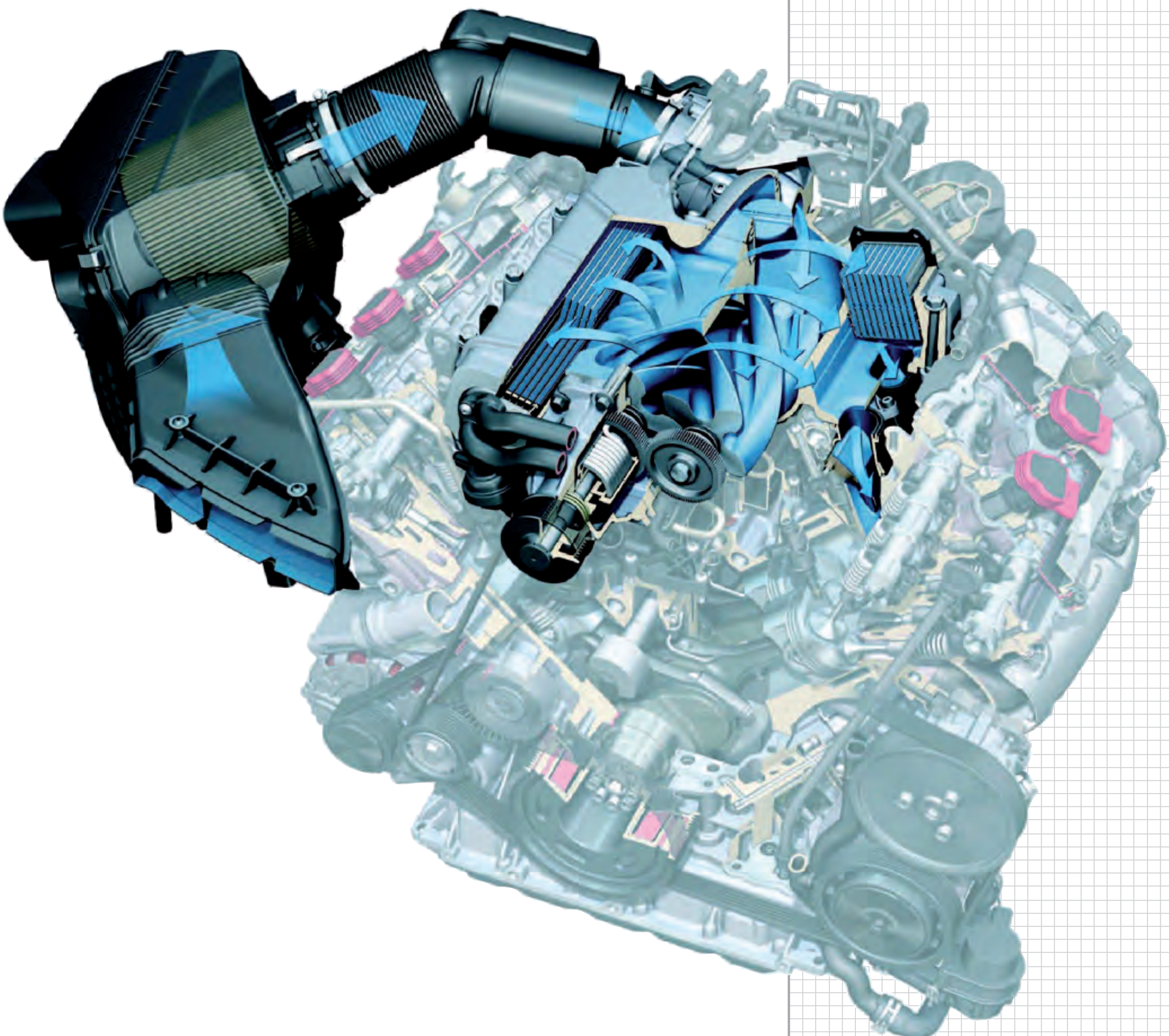
During the drive link test, the pump operates at different speeds and the engine control module evaluates the results. The drive link check must not therefore be interrupted.

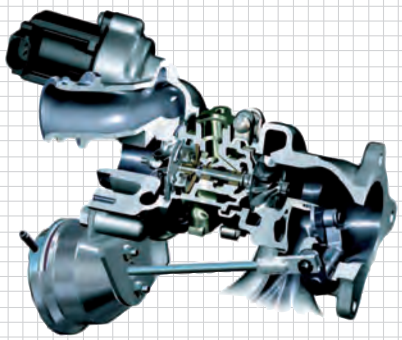
!

Please refer to the repair guidelines for more detailed information on coolant pump diagnosis.

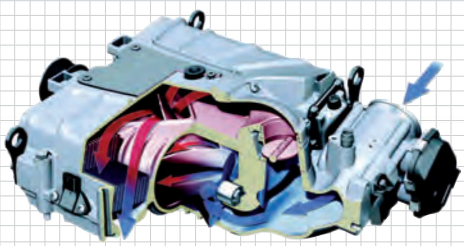
Air guide

The central component of the air supply system is the **air-charging module** installed in the inner V of the engine, which contains the **supercharger bypass control** and **charge-air cooling system.**





Turbocharger



Supercharger (Roots blower)

The following criteria are crucial for a decision in favor of a mechanically powered compressor:

- High comfort requirements
- Powerful drive-off characteristics, wide range of uses, from comfort-oriented to very sporty
- The engine can be used in several vehicle models due to its characteristics
- Fulfills all current emission standards as well as standards EU5 and ULEV II, which will come into effect in the near future

Advantages and disadvantages of mechanical turbocharging with a Supercharger compared to turbocharging with an exhaust turbocharger

Advantages:

- Boost pressure available immediately when required
- Boost pressure delivered continuously and increased in line with the engine speed
- The charge air does not require such intensive cooling
- Extended service life, low-maintenance operation
- Compact design (space-saving installation in the inner V in place of the intake manifold)
- Low fuel consumption
- Fast, dynamic torque build-up, early peak torque for good drive-off characteristics
- Air travels short distances into the cylinder prior to compression, which results in an extremely low air volume and spontaneous drive-off characteristics
- Improved engine emissions. Reason: The catalytic converter reaches operating temperature more quickly. On a turbocharged engine, some of the heat energy for powering the turbocharger is lost

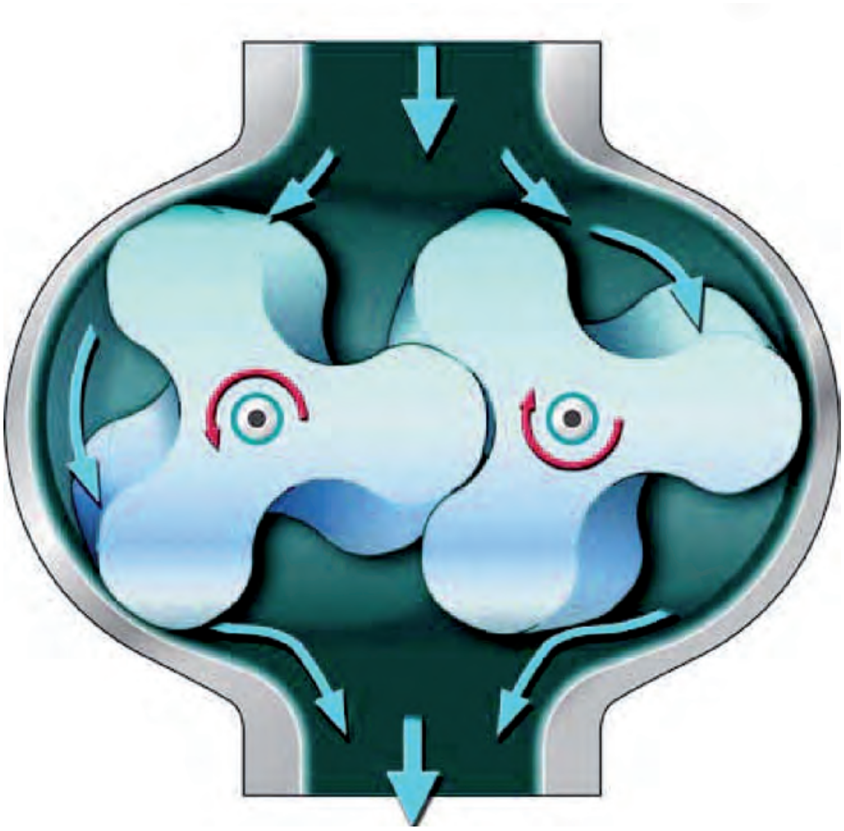
Disadvantages:

- Very complex manufacturing process due to very tight manufacturing tolerances (rotors in relation to the housing and one another)
- Extremely sensitive to the intake of foreign debris in the clean air section
- Relatively heavy
- Complex measures required for sound insulation
- Some engine power is lost when the blower is powered

Supercharger

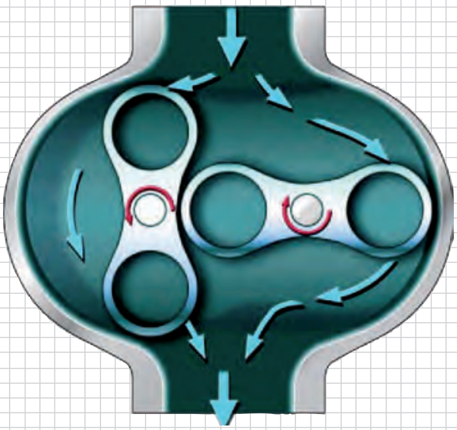
Operating principle of the supercharger (Roots blower)

Roots blowers have a similar design to rotary piston machines and operate without internal compression according to the principle of positive displacement. The fan consists of a housing that contains two rotating shafts (rotors). The two rotors are powered mechanically via a belt connected to the crankshaft. Both rotors are connected synchronously to a gear stage outside the housing and rotate in opposite directions to one another. The diagram below shows how the rotors mesh together.

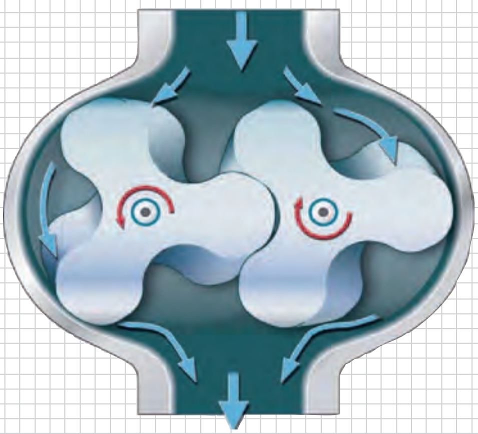


The fan must be designed in a such a way that the rotors form a seal with the housing and with one another and generate as little friction as possible. During operation (when the rotors turn), air is conveyed from the air inlet (intake side) to the air outlet (pressure side) between the vanes. A backflow effect pressurizes the conveyed air.

Different models of Roots blower



Older versions of Roots blower were fitted with twin-vane rotors.



Modern versions such as those used in the combustion engine on the Cayenne S Hybrids have three vanes and a screw shape in order to achieve a higher boost pressure and a higher level of consistency (greater overall efficiency).

Historical development

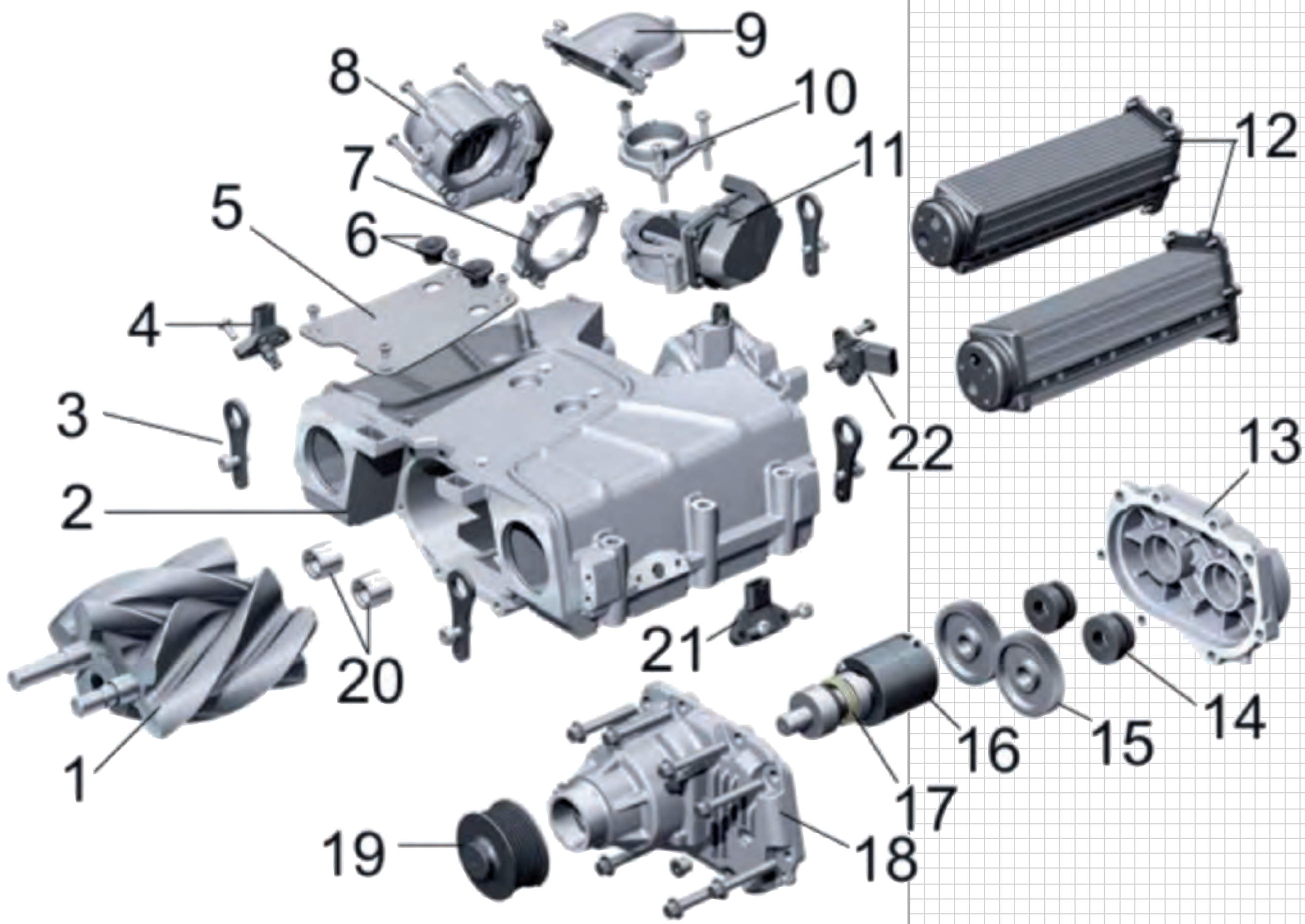
The name of the system originates from brothers Philander and Francis Roots, who patented the principle in 1860. At the time, Roots blowers were used primarily to generate currents of air for blast furnaces, but were subsequently used in other branches of industry. The first motor vehicle manufacturer Gottlieb Daimler installed a Roots blower in a vehicle engine in 1900. In the 1920s and 1930s, Roots blowers gained a foothold in the world of motor sport. One special characteristic of these engines was the typical screeching sound of the compressor. However, the importance of the Roots blowers dwindled with the development of temperature resistant materials and the introduction of the turbocharger. Today, Roots blowers are mainly used in sports vehicles.

Air-charging module

Modern Roots blowers such as the one used in the Cayenne S Hybrid models are screw-type superchargers. Unlike the previous generation of three-vane rotors, the rotors on Roots blowers installed in the Cayenne S Hybrid have four vanes. Each vane on the two rotors is tilted at an angle of 160° in relation to the longitudinal axis to guarantee a continuous flow of air and reduce pulsation. The Roots blowers are manufactured by EATON, a company that already has many years of experience in the manufacture of Roots blowers.

Design

The entire air-charging module is located in the inner V of the engine so the engine has a flat design. The total weight of the module is 39.6 lbs/18 kg (excluding coolant filling).



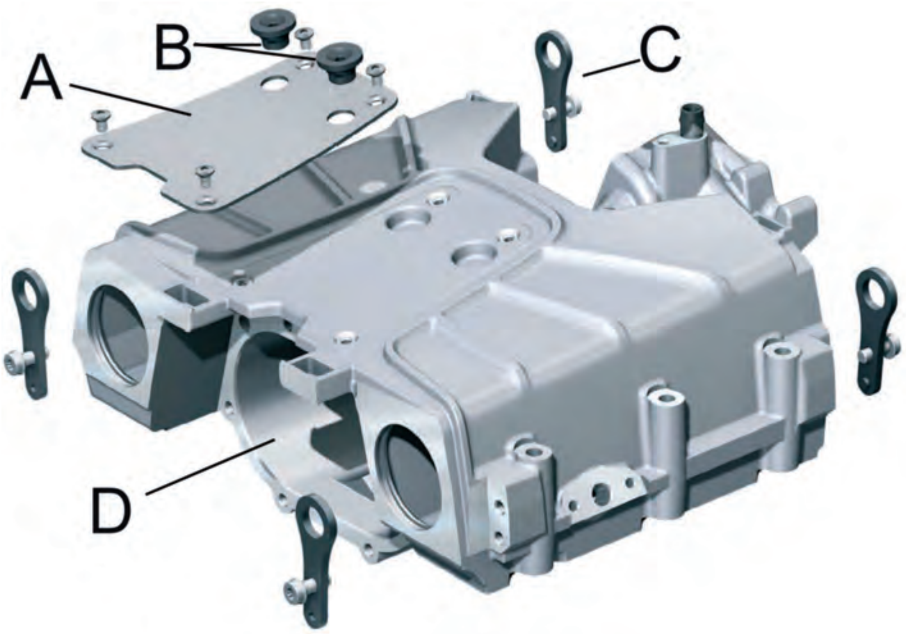
1 Rotors
2 Housing
3 Shackle for transportation
4 Boost pressure sensor/
Intake manifold temperature
5 Damping plate
6 Plug coupling for designer cover
7 Adapter
8 Throttle unit
9 Bypass elbow
10 Bypass valve adapter
11 Bypass valve unit
12 Charge-air intercooler
13 Bearing cover
14 Front roller bearing
15 Synchronous gear wheels
16 Decoupling element
17 Drive shaft
18 Drive housing
19 Pulley
20 Rear rotor bearing
21 Boost pressure sensor
22 Intake air temperature

Housing

The supercharger, an electrically controlled bypass valve and a charge-air cooler for each cylinder bank are integrated in the single-part cast housing. The air vents to the individual cylinders are located on the underside of the housing. The transportation shackles attached to the air-charging module are used to suspend the engine during installation and removal.

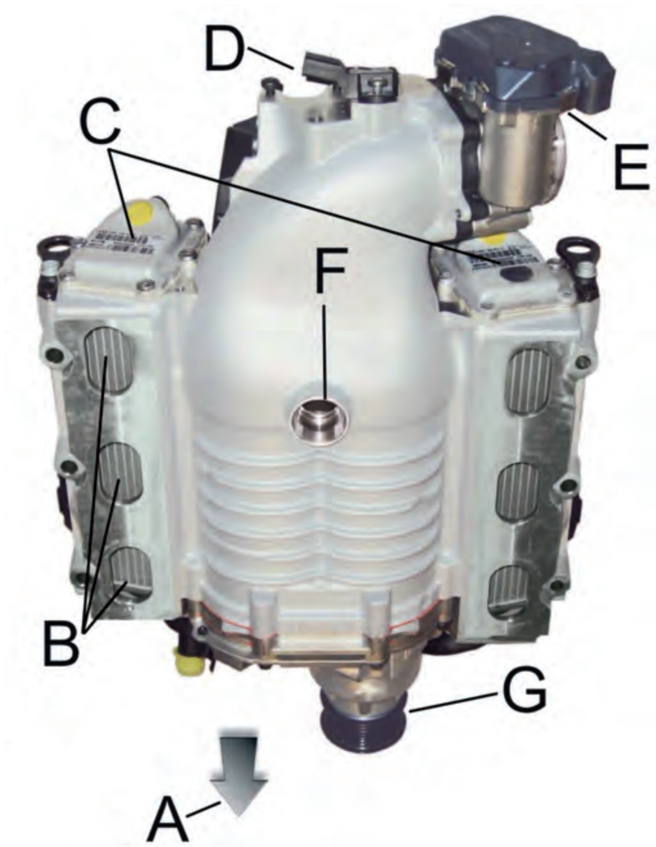
Top section of supercharger

A Damping plate
B Plug coupling for design cover
C Shackle for transportation
D Housing



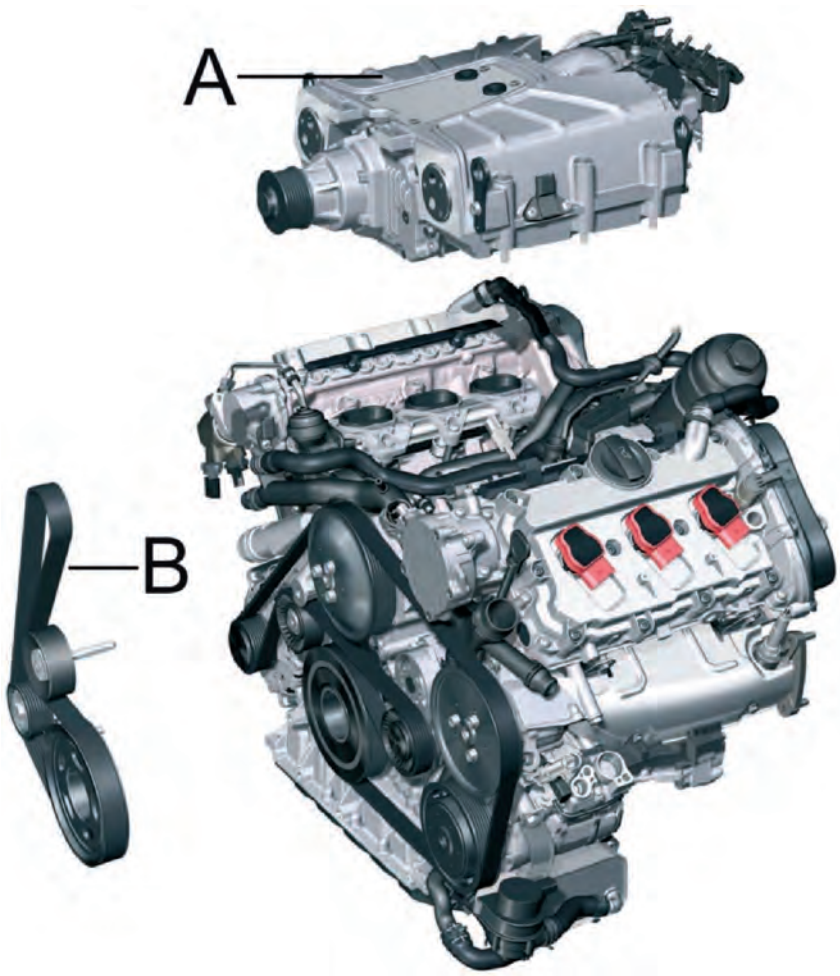
Bottom section of supercharger

A Direction of travel
B Air outlet
C Charge-air cooler
D Intake manifold pressure and intake air temperature sensor
E Throttle valve control unit
F Point of entry for positive crankcase ventilation
G Drive shaft



Drive

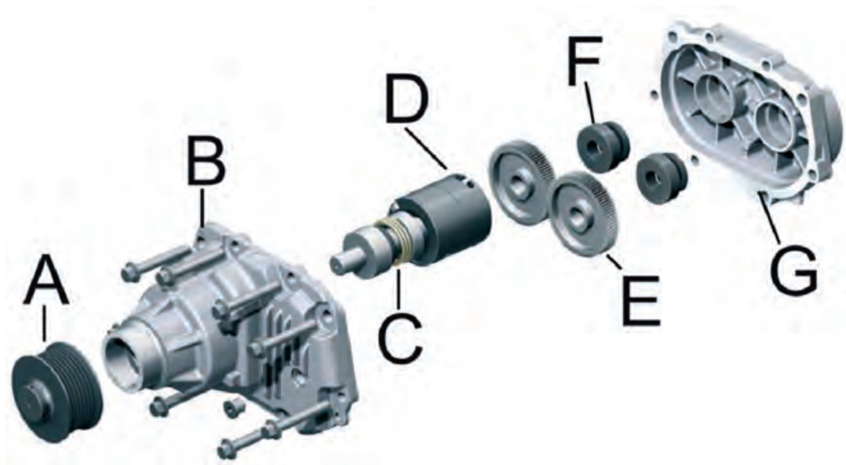
The supercharger is powered by the crankshaft via the second groove of the belt pulley. The blower is driven permanently and is not engaged or disengaged by a magnetic clutch. Both drives are isolated from the crankshaft vibrations by a rubber layer in the joint torsional vibration damper, resulting in an improvement of the resonance characteristics at low speeds and at full throttle. Side effect: the load on the belt is reduced significantly. The ratio between the crankshaft and the air-charging module is 1:2.5, allowing a maximum speed of 18,000 rpm.



A Air-charging module
B Supercharger drive

The illustration shows a conventional combustion engine that operates without an E-machine (**not hybrid,** the auxiliary units are omitted on the Cayenne S Hybrid).

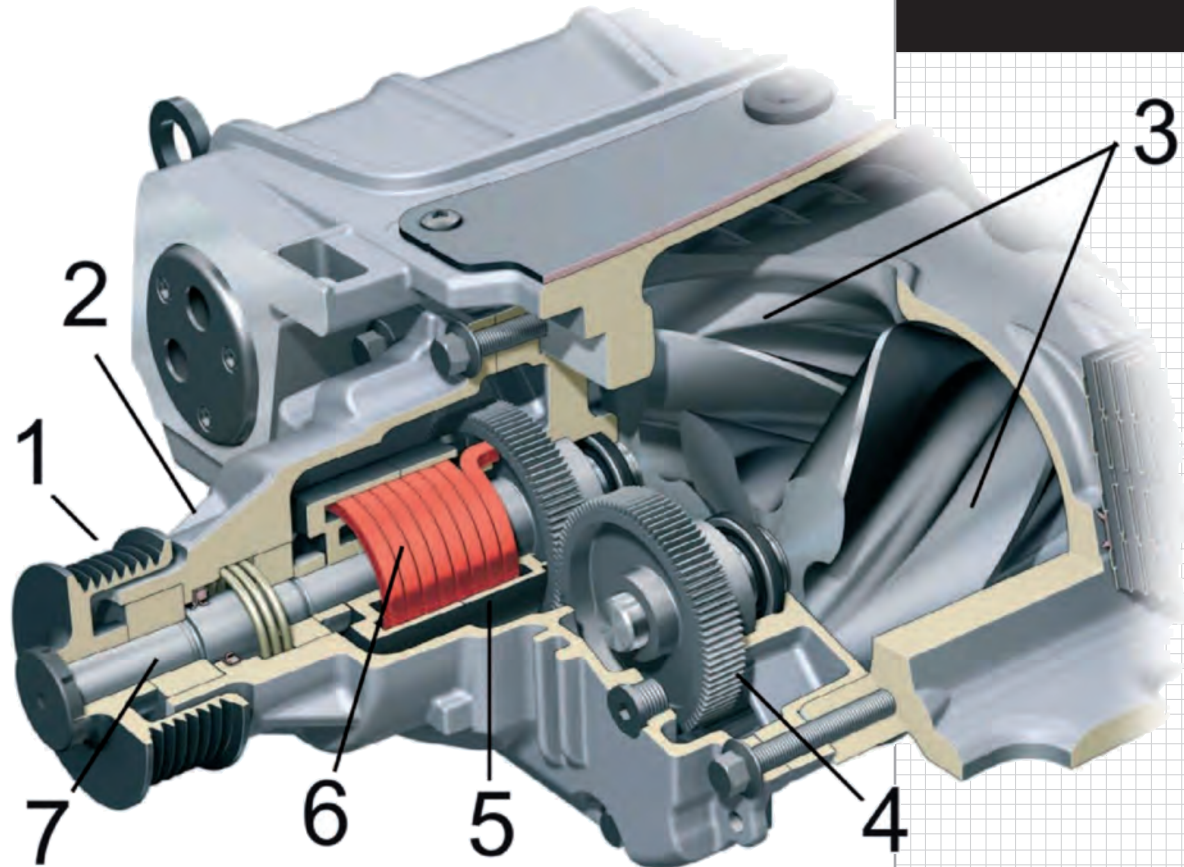
The supercharger is coupled via the decoupling element (SSI Single Spring Isolator). This decoupling element is integrated in the drive housing on the air-charging module and acts as a spring element. The element was designed to optimize the flow of power during load changes in order to enable the drive belt to run more smoothly (optimized acoustics) and extend the belt service life.



A Pulley
B Drive housing
C Drive shaft with mount
D Decoupling element (SSI)
E Synchronous gear wheels
F Front roller bearings
G Bearing cover

Function

In the drive housing of the supercharger the torsion spring is guided by an input and output bush. The spring transfers the drive torque of the pulley to the gear stage. The input and output bushes limit vibration displacement in the same direction and opposite direction that the supercharger is rotating. The spring element was designed to be "soft" enough to decouple efficiently, but avoid hard impacts during load changes in dynamic mode, which could cause interference noise. Further down the drive train, the second rotor is powered via a pair of gear wheels that ensure fully synchronous rotation of the two rotors in opposite directions to one another. The large number of teeth on the gears reduces the transmission of vibrations. The manufacturer presses the gear wheels onto the rotor shafts using a technique that requires special gauges. The wheels must fit accurately, otherwise the rotor vanes will collide with one another. For this reason, the gear wheels must not be forced from the shafts during repair work. The drive head is filled with a special oil.

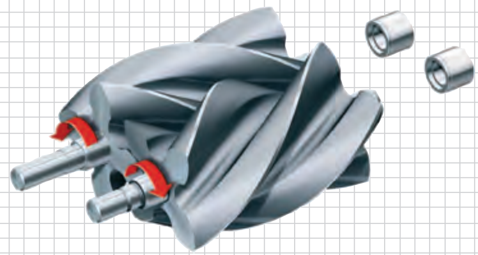


Cross section of the air-charging module

1 Pulley	2 Drive housing	3 Rotors
4 Synchronous gear wheels	5 Input bush	6 Torsion spring
7 Drive shaft with mount		

Rotors

The four-vane rotors are twisted at an angle of 160°. Both rotors rotate inside maintenance-free antifriction bearings. The rotors are covered with a graphite layer that keeps wear to a minimum during the run-in period. The coating seals the rotor to prevent air from leaking out (rotor to rotor and rotor to rotor bore).



Rotors and rotor bearings

The engine control unit functions and associated load control and injection system functions as well as the relationship between the fuel supply, exhaust system, ignition timing angle calculation and diagnosis are described in Chapter 2 DME engine electronics.

Control of the air flow and boost pressure

The supercharger is powered full-time. If there were no boost pressure control available, the supercharger would always generate the maximum air flow and therefore also the maximum boost pressure for the respective speed. However, as charge air is not required under all operating conditions, this would result in excessive air build-up on the pressure side of the blower, which would lead to an unnecessary loss in engine power. It must therefore be possible to control the boost pressure. A regulating valve control unit controls the boost pressure of the Cayenne S Hybrid engine. It is screwed into the air-charging module and connects the pressure side of the supercharger to the intake side. When the bypass valve is opened, some of the delivered air volume is returned to the intake side of the supercharger via the open bypass. The function of the bypass valve is similar to that of a wastegate valve on a turbocharged engine.

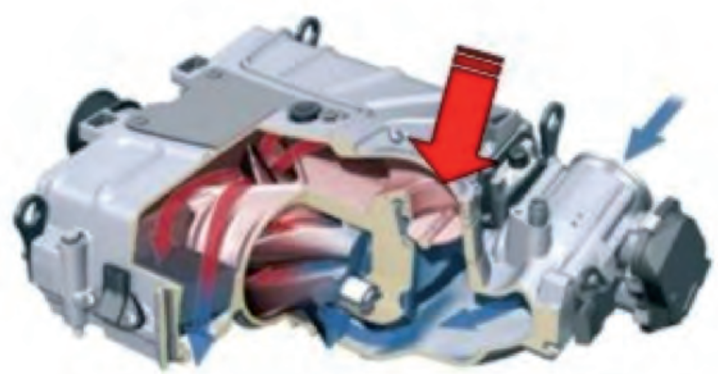
Tasks of the regulating valve control unit:

- Regulation of the boost pressure specified by the engine control unit
- Limitation of the maximum boost pressure to 27.5 psi (1.9 bar) absolute

Function

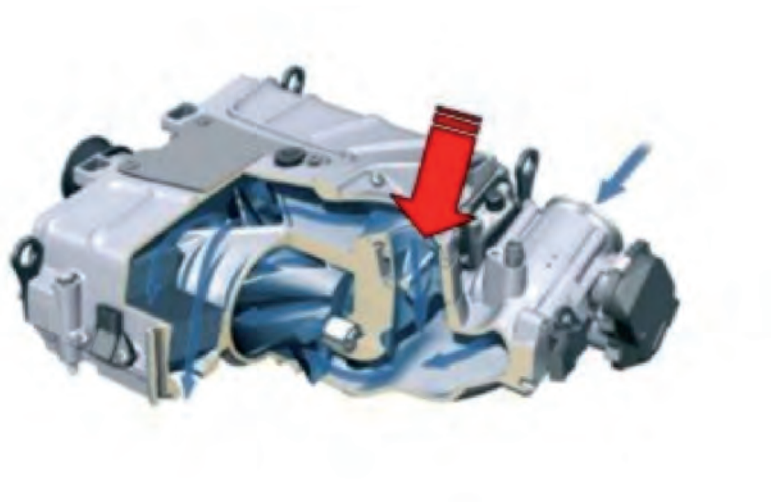
Full throttle (bypass valve closed)

At full throttle, the air flows to the engine via the throttle valve, supercharger and charge-air cooler.



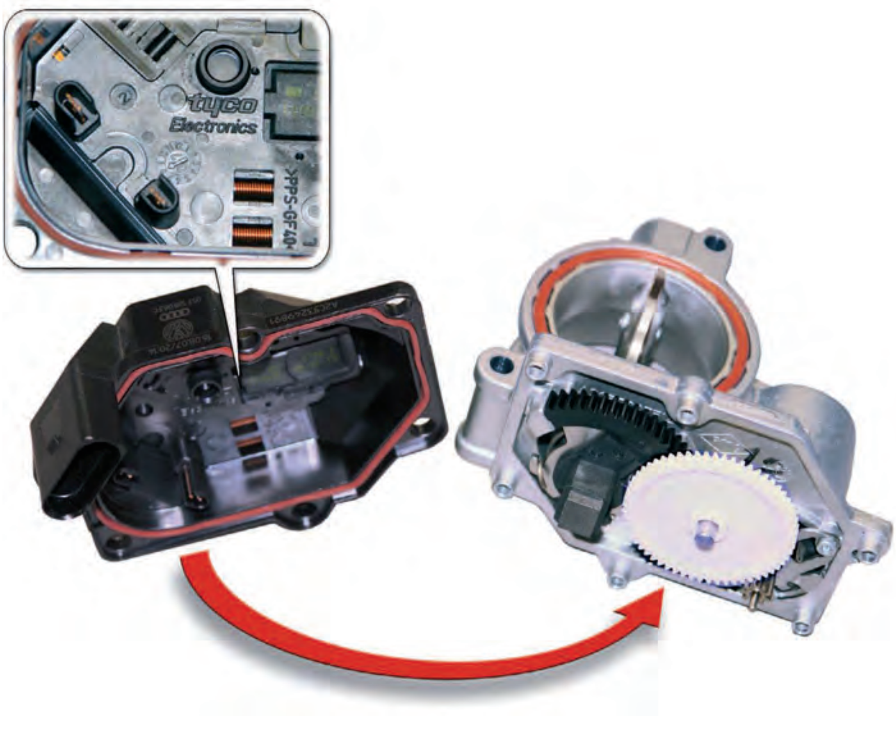
Partial load (bypass valve open)

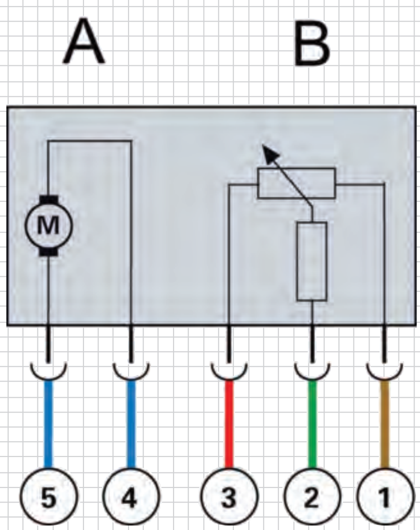
At partial load, idling speed and in deceleration, some of the delivered air volume is returned to the intake side through the open bypass valve.



Bypass valve control unit

An expensive, complex magnetic clutch mechanism for deactivating the drive belt can be omitted by installing a regulating valve control unit. The power consumption of the air-charging module is between 1.5 kW and 38 kW depending on the engine speed.

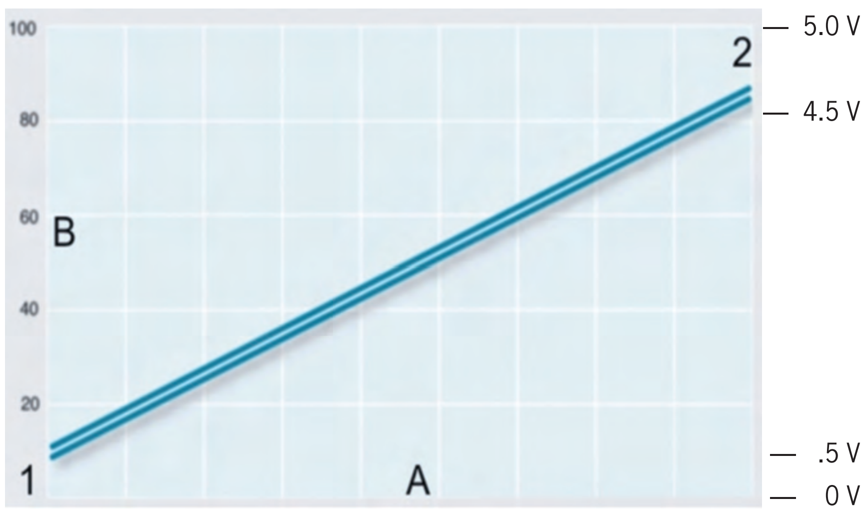




Signal image of the potentiometer for the bypass valve

A Servo motor, bypass valve
B Potentiometer for bypass valve
1 Sensor ground
2 Control signal
3 Sensor voltage
4 Bypass valve motor supply voltage
5 Bypass valve motor ground

Signal image of the potentiometer for the bypass valve



1 Lower mechanical stop
2 Upper mechanical stop
A Sensor path
B Sensor signal in %

Potentiometer for bypass valve

This component detects the current bypass valve position. It is installed inside the cover of the adjuster housing and has an output voltage range between 0.5 V and 4.5 V. The potentiometer operates according to the magnetoresistive measuring principle and is therefore insensitive to electromagnetic radiation.

Signal utilization

The feedback signal from the bypass valve position is used to define the regulator input values. It is also used to determine the adaptation values of the bypass valve unit.

Effects in the event of signal failure

The valve is de-energized and moves spring-loaded to the open stop. The fault is irreversible for one driving cycle. No boost pressure is built up in this case. Neither the full power nor the full torque are available. The component is relevant to OBD, which means that the Check Engine warning light (MIL) switches on in the event of a failure.

Sensors for measuring the mass air flow and the boost pressure

The main control variables for controlling the boost are

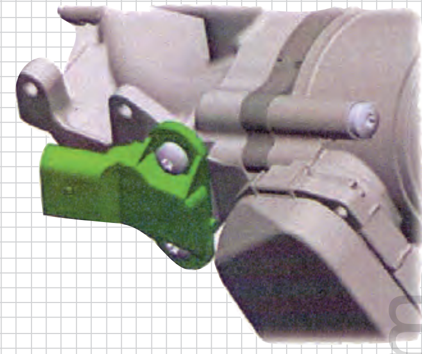
- the mass air flow and
- the boost pressure.

Three sensors with identical functionality are installed for this purpose. They measure the intake air temperature and the intake manifold pressure. The first sensor is located upstream of the throttle valve control unit. This sensor is a double sensor, i.e. two individual sensors are enclosed in one housing:

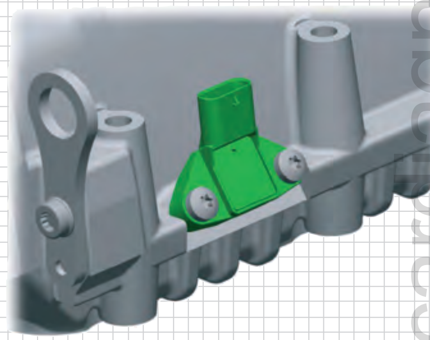
- Intake air temperature sensor
- Intake manifold pressure sensor

The second and third sensor are identical in design and installed on the left and right of the air-charging module. They measure the pressure and the temperature of the air in each cylinder bank separately. The important factor here is that the measuring point is behind the charge-air coolers. The measured values then actually correspond with the values of the mass air flow in the cylinder banks. The following sensors are used:

- Load pressure sensor, cylinder bank 1
- Intake manifold temperature sensor, cylinder bank 1
- Load pressure sensor, cylinder bank 2
- Intake manifold temperature sensor, cylinder bank 2



The first sensor located upstream of the throttle vavle control unit.



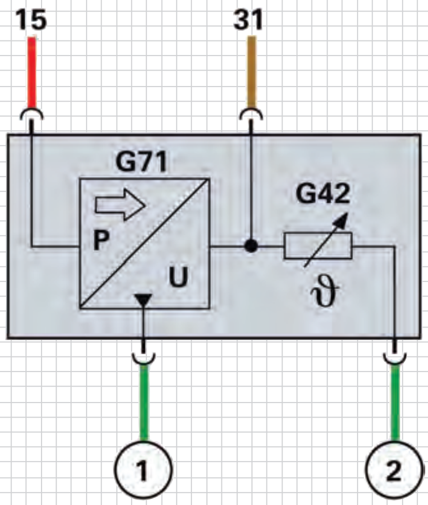
Sensors 2 and 3 on the air-charging module (sensor 3 pictured).

Circuit

The intake air temperature sensor is a sensor with negative temperature coefficient (NTC). A resistance that corresponds to the current temperature of the sensor influences the voltage signal sent to the engine control unit.

Legend:

G42 Intake air temperature sensor
G71 Intake manifold pressure sensor
15 Terminal 15
31 Terminal 31
1 Intake manifold pressure signal
2 Intake air temperature signal



Signal utilization

The signal from the intake manifold sensor upstream of the throttle valve control unit is used to anticipate the required position of the bypass valve. This is necessary for regulating the desired boost pressure. The required position of the bypass valve depends very much on the pressure level upstream of the air-charging module.
The two boost pressure sensors are used to regulate the boost pressure to the required value as well as calculate the mass air flow for each working cycle using the sensor output signals. This mass air flow determines the injection quantity, injection timing and ignition timing angle and is an important input value for torque-based engine control.

Effects in the event of signal failure

The Check Engine light (MIL) switches on when a failure occurs. Failure of the intake manifold pressure sensor leads to irregular regulation of the boost pressure. Boost pressure sensor failures can lead to an incorrect calculation of the mass air flow resulting in an incorrect mixture composition across the entire load/engine speed range. The injection quantity will also be incorrect. The combination of these failures has a negative effect on emissions as well as power development. In boost mode, a defect on this sensor could result in incorrect boost pressures which could lead to destruction of the engine. A diagnosis of all sensors is therefore run after the ignition is switched on. If any anomalies are identified, a corresponding entry is made in the fault memory and the system switches to an "equivalent" sensor or the replacement model. As a result, the system behaves in the normal way as far as possible and consequential damage is avoided.

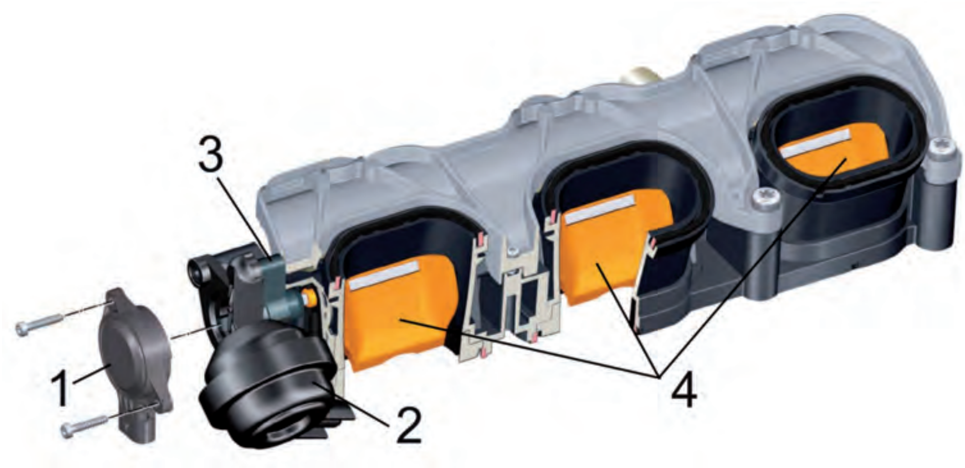
The engine control unit functions and associated load control and injection system functions as well as the relationship between the fuel supply, exhaust system, ignition timing angle calculation and diagnosis are described in Chapter 2 DME engine electronics.

Load control

The bypass valve control unit works in combination with the throttle valve control unit. When this control was developed, particular importance was attached to achieving throttle-free operation as much as possible along with superior power development. In the part-load/intake range, the bypass valve is opened throttle-free and the engine throttle valve is responsible for the load control. In the boost pressure range, the bypass valve is responsible for the load control and the engine throttle valve opens fully.

Intake manifold flaps

The engine on the Cayenne S Hybrid uses intake manifold flaps to improve the internal mixture formation. They are located in an intermediate flange between the air-charging module and cylinder head.



Intake manifold flap module, left cylinder bank 2

1 Potentiometer for intake manifold flap
2 Vacuum unit
3 Actuator on the intake manifold flap shaft
4 Intake manifold flaps

Valve for intake manifold flap

The intake manifold flaps, which are secured on a common shaft, are actuated by a vacuum unit. The required vacuum is applied by the valve for the intake manifold flap. The engine control unit actuates the valve for the intake manifold flap according to the map.

Effects in the event of failure

No vacuum is applied if an intake manifold valve is not actuated or is faulty. In this state, the intake manifold flaps close the duct in the cylinder head via the spring force of the vacuum unit. The engine power is thus reduced.

!

When the intermediate flange is assembled, the intake manifold flaps must be set to power position (intake duct open).

Valve for intake manifold flap

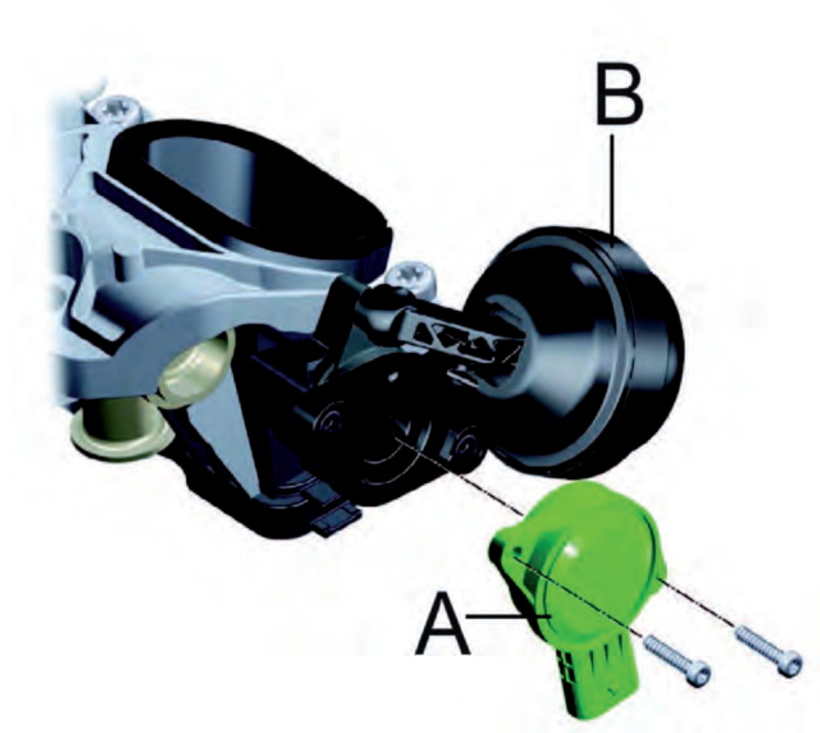
Potentiometer for intake manifold flaps

Two sensors monitor the position of the intake manifold flaps:

– Cylinder bank 1: Potentiometer for intake manifold flap 1

– Cylinder bank 2: Potentiometer for intake manifold flap 2

The sensors are integrated directly in the flange of the vacuum unit. They are contactless torque angle sensors, which operate according to the Hall sender principle. The sensor electronics generate a voltage signal that is evaluated by the engine control unit.



Potentiometer for intake manifold flap control

A Potentiometer B Vacuum unit

Signal utilization

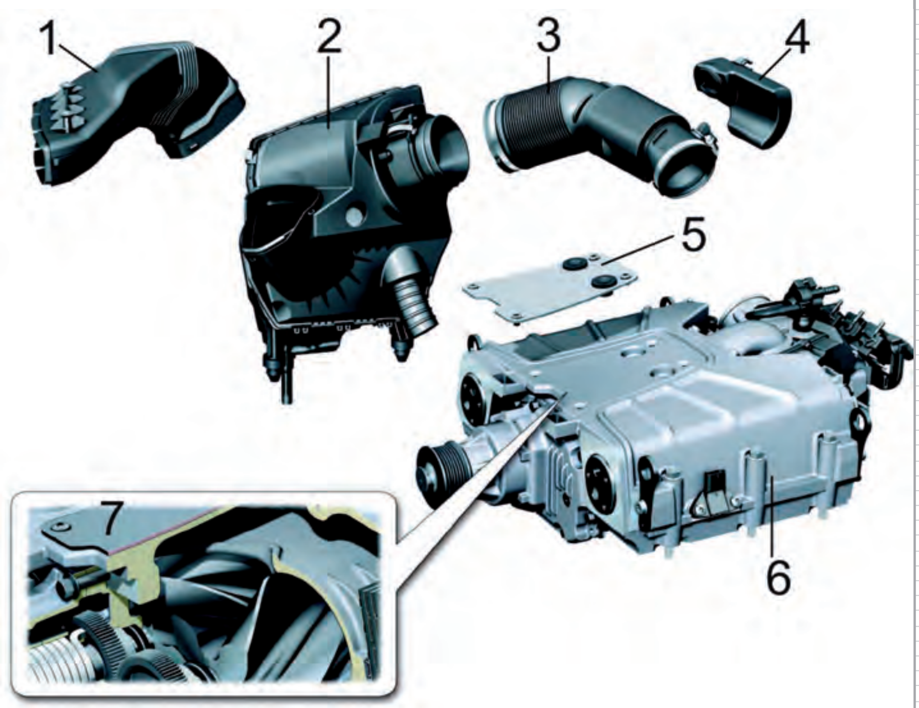
The signal monitors the position and is used for diagnostic purposes.

Effects in the event of signal failure

The position is no longer detected correctly. A diagnosis is no longer possible. The component is relevant to OBD, which means that the Check Engine warning light (MIL) switches on in the event of a failure.

Sound insulation of the supercharger

One other objective during the development of the engine was to minimize the noise generated by the supercharger. This objective was successfully achieved by making modifications to the housing design. A multilayer damping plate acts on the gas discharge vent on the supercharger. Additional measures in the intake area also make a contribution to reducing noise (see figure). Other sound insulation features include insulating mats positioned under the air-charging module.

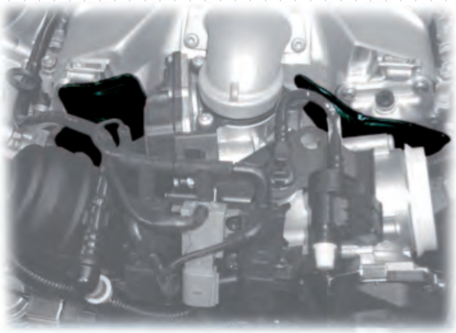


Air-charging module with sound insulation features

1 Unfiltered air intake
2 Air filter with foam mat
3 Filtered air intake with broadband damper
4 Helmholtz resonator
5 Multilayer damping plate
6 Air-charging module
7 Oil discharge opening

Note!

Helmholtz resonator is used to reduce the noise levels (in this instance) by the use of sound deadening material, or possibly slots or openings within the unit.



Insulating mats

Several sound insulation mats are located between the air-charging module and the cylinder head or block. These mats provide sound insulation for the area under the supercharger. Two small insulating inserts are located on the back of the air-charging module.

Other insulating mats are located under the air-charging module in the inner V of the engine. While a larger mat is positioned between the two intake manifolds, two narrower insulating mats are inserted laterally between the intake manifolds and the cylinder heads.


S VM 9200


PORSCHE
Cayenne S
S VM 9200

2 DME hybrid technology

General

The present state of full electric vehicle technology, storage of energy in nickel hydride batteries, super capacitors or lithium ion batteries does not provide a consumer acceptable solution due to range and space considerations. The combination of combustion engine as a provider of mechanical energy and electric motor as a drive or generator of electrical energy offers a genuine alternative, in particular over short driving distances.

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The advantages of a fully electric concept:

- High degree of efficiency
- Minimal space requirements
- Torque available from engine speeds of 0 rpm

can be combined with the long-range capabilities of the combustion engine. Porsche is the first manufacturer to bring a parallel full hybrid vehicle onto the market.

The drive concept of the Porsche Cayenne S Hybrid delivers the sporty performance of an 8-cylinder engine while achieving the consumption and emission values of a 6-cylinder engine.

Important!

Safety instruction

The safety instructions must be observed during work on the Cayenne S Hybrid.
All work on hybrid vehicles may only be performed by qualified staff.
For further information, see:

- the chapter "High-voltage safety" in the “Cayenne S Hybrid Training Information” and the
- “PIWIS Information System”.

Hybrid principles

Historical development

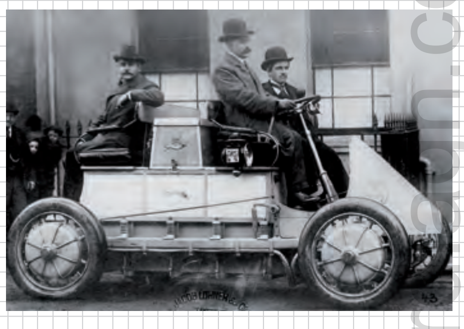
Wheel-hub motor

In 1893 at the age of 18 while working for the Béla Egger Vereinigte Elektrizitätswerke AG in Vienna (later to become Brown Boveri), Professor Ferdinand Porsche developed an electric wheel-hub motor that he then patented in 1896. The motor was installed in a vehicle that had very similar characteristics to an electric vehicle because the wheel-hub motor was the only motor to drive the vehicle. NASA used wheel hub motors years later when constructing the Lunar Rover moon buggy.

Lohner-Porsche electric car

Three years later in 1899, Ferdinand Porsche developed the Lohner-Porsche electric car at the Ludwig Lohner & Co. royal carriage factory in Vienna.

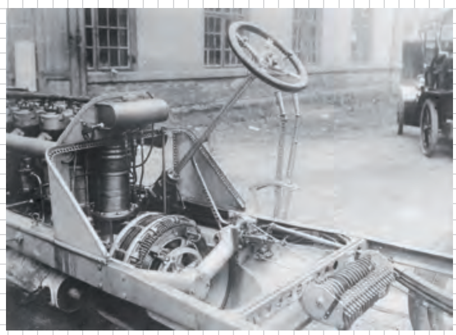
The vehicle had two electric wheel-hub motors on the front axle and reached a top speed of 30 mph (50 km/h), which was quite remarkable at the time. Equipped with a 904 lbs (410 kg) lead battery, the electric car had a maximum range of 30 miles (50 km). In 1900, the Lohner-Porsche electric car was presented at the World Trade Fair in Paris and was celebrated as a ground-breaking innovation.



In 1900, he built a racing version with wheel-hub motors fitted on the rear axle for Englishman E. W. Hart. In September 1900, the car was the first all-wheel drive vehicle in the world.

Lohner-Porsche Mixte

To compensate for the disadvantages of the heavy batteries, Porsche combined the electric drive with a 15 hp four-cylinder engine coupled with an 80-volt dynamo. This generator supplied current to the electric wheel-hub motors integrated in the front wheels - either directly or via the battery charged simultaneously by the generator.



Presented to the public in 1902, the Lohner-Porsche Mixte was the first motor vehicle with a hybrid drive.

Hybrid selling points

A characteristic torque curve of a combustion engine has a maximum torque in the mid-speed range and a very low torque at idling speed that is to insufficient to move the vehicle from a standstill.

Compared with the characteristic curve of a combustion engine, the characteristic curve of an E-machine reaches maximum torque at a speed of 0 rpm. Unlike a combustion engine operating at idle speed, the E-machine does not idle or consume energy and produce emissions when the vehicle is at a standstill.

The E-machine assists the combustion engine at moments when engine design weaknesses are exposed: in the low speed range. With assistance from the E-machine, the combustion engine can always be used in the most effective operating range. This shift in the load point increases the efficiency of the drive concept. The combination of these two drive variants provides clear advantages in urban driving environments where frequent driving-off manoeuvres are made and full throttle is rarely used.

Electric motors

All electric motors consist of a fixed stator and a rotor that rotates inside the stator. The rotary movement of the rotor is generated by the reciprocal action between the magnetic fields on the rotor and stator, which combine to produce a torque. Coils are integrated in either the stator, rotor or both components, depending on the motor type. In the illustration, the magnetic field around the rotor is generated by a permanent magnet, for example, which makes the design of the overall system much simpler.

The following motor characteristics change depending on the circuit and design of the coils in the stator and rotor:

- Direct-current, alternating-current or three-phase motor
- Starting current
- Load behavior
- Rotational direction control and speed control

Not every electric motor can be operated as a generator. If it is wished to avoid installation of two components in the vehicle (electric motor and generator), the number of motor types that can be used in hybrid vehicles is restricted considerably.

Direct-current motors

Good starting and control characteristics are standard features of direct-current motors. The rotor speed depends directly on the extent of the supply voltage and is therefore extremely easy to regulate.

The typical design of a direct-current motor includes a permanent magnet for the stator, while the operating voltage is supplied to the rotor coil via carbon brushes. When the motor is switched on, the rotor rotates until the rotor magnetic field is aligned with the stator magnetic field. In order for the rotor to continue rotating, the polarity and therefore the direction of the magnetic field in the rotor must be changed via the commutator. In the above example, the polarity is changed every 180° to ensure the rotor continues rotating.

On the 2 pole and 4-pole motors, a significant imbalance is generated during operation so a much larger number of poles is required in practice. The commutator generates the correct polarity so that the rotor can continue to rotate.

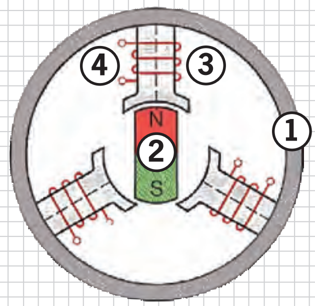
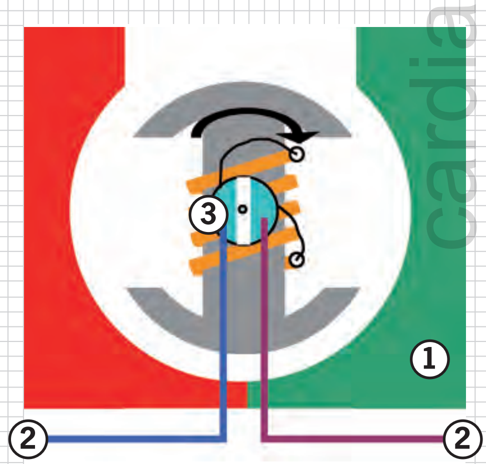
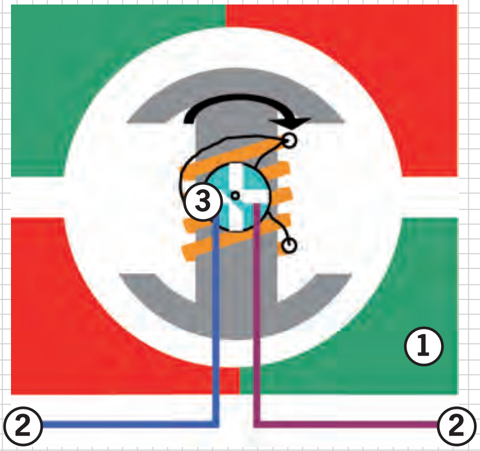


Diagram of three-phase motor
1 Stator
2 Rotor
3 One of 3 stator coils
4 Coil connections



Two-pole motor
1 Stator
2 Commutator and carbon brushes
3 Connections



Four-pole motor
1 Stator
2 Commutator and carbon brushes
3 Connections

The different driving situations that arise in hybrid driving mode such as:
- alternating load
- frequently fluctuating speed
- operation as motor and generator
- relatively high performance

require a much more complicated design than the one illustrated. In order to reverse the rotation direction or operate the generator, for example, the power electronics must ensure varied switching of the rotor and stator coil. Even if the direct current from the high-voltage battery in the vehicle cannot be converted to an alternating or three-phase current, the voltage must still be adapted in order to achieve different speeds and torques.

However, additional problems caused by wear and friction on brushes and slip rings are encountered in driving mode.

In conclusion, the use of direct-current motors in hybrid vehicles is not an option for precisely the reasons stated above.

Installation locations for direct-current motors used in motor vehicles include:
- Wiper motors
- Fan motors
- Drive links
- Starter motor

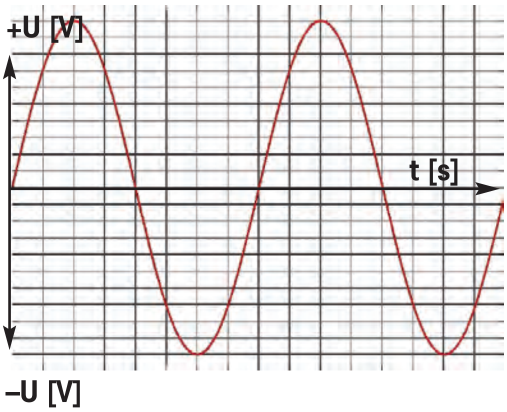
Due to their high starting torques and simple speed control via the operating voltage, direct-current motors are typically installed as drive motors for rail vehicles or used in applications where only direct current energy is available and requirements are not demanding enough to justify converting the DC current into an alternating/three-phase current.

Brushless direct-current motors

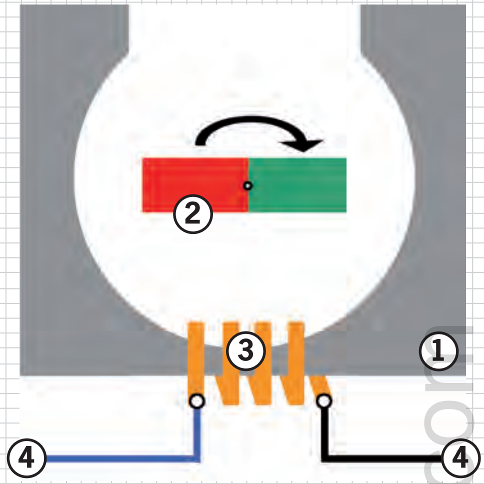
Brushless direct-current motors are identical in design to synchronous motors (see below), but require integral control electronics to convert the direct current into a suitable alternating current or three-phase alternating current. The three-phase synchronous motor with power electronics used in hybrid technology can also be classed as a "brushless direct-current motor".

Alternating-current motors

On alternating-current motors, the polarity of the alternating current from the stator coil reverses the polarity of the rotor magnetic field automatically (see illustration).



The slip rings or carbon brushes required on the direct-current motor are omitted as a result of the omission of the commutator and current supply to the stator coil. If the rotor has only just started moving, the rotation speed depends on the frequency of the alternating current, whose voltage level defines the maximum power that can be generated. However, the alternating current itself is not sufficient to achieve the curve shown in the image above. The so-called starting motor requires an initial impulse ("starting impulse") in order to initiate a clockwise or counter-clockwise rotation.



Alternating-current motor (starting motor)

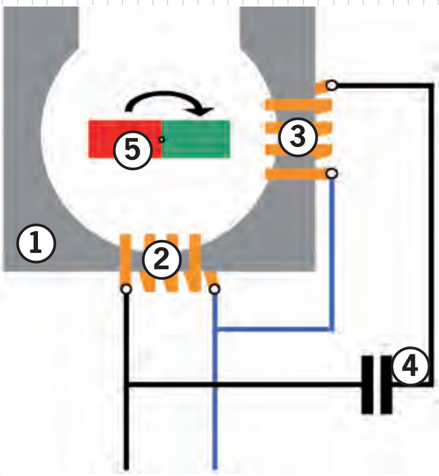
1 Stator
2 Rotor
3 Stator coil
4 Connections

The number of poles is increased by distributing the coil around the stator. The nominal speed for all alternating-current/three-phase motors is calculated using the following formula:

$$n = \frac{f\,(Hz) * 60\left(\frac{s}{min}\right)}{p}$$

f = frequency and p = number of pole pairs. At a frequency of f=50 Hz, the nominal speed of a motor with two pairs of poles would be –> n=1500 rpm. The speed of an alternating-current or three-phase motor is therefore modified by varying the frequency.

To allow an alternating current motor to start autonomously, a rotary field must be generated that carries the rotor along. On simple alternating-current motors, this is always achieved during an auxiliary phase generated by a capacitor. The “second“ generated operating voltage is applied to another stator coil, which allows the motor to start automatically and determines the direction of rotation. The “capacitor motor“ is used in almost all electric devices operated with 240 V AC power supply. The design of the motor is simple but unsuitable for applications requiring high levels of power.



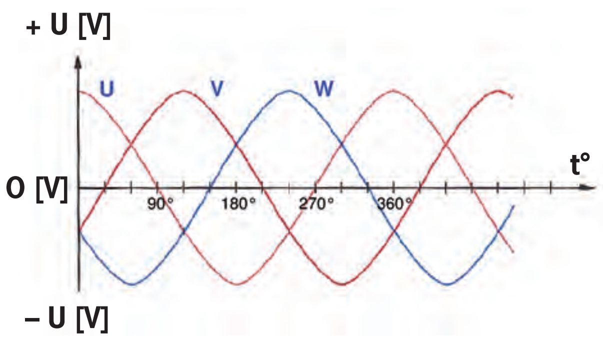
Alternating-current motor with auxiliary phase
1 Stator
2 Stator coil
3 Stator coil for auxiliary phase
4 Capacitor
5 Rotor

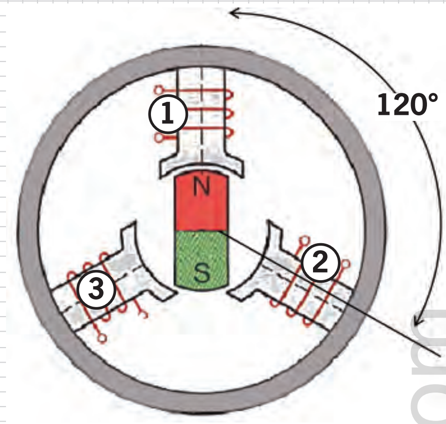
Three-phase motors

Three-phase currents and even three-phase alternating currents are produced by generators with a stator containing three coils offset at 120°. Three alternating currents offset at 120° with the same frequency are available at the terminal clamps on the stator coils.

In motor vehicle/hybrid technology, these three phases are referred to as u, v and w. The connections for these three coils are often designated as u1, u2, v1, v2 and w1, w2.

The voltage/time diagram below clearly shows the phase offset. The time t is specified in degrees here. The full circle of 360° represents a complete phase of the sinusoidal signal waveform.





Three-phase motor

1 Stator coil u (connections u1, u2)
2 Stator coil v (connections v1, v2)
3 Stator coil w (connections w1, w2)

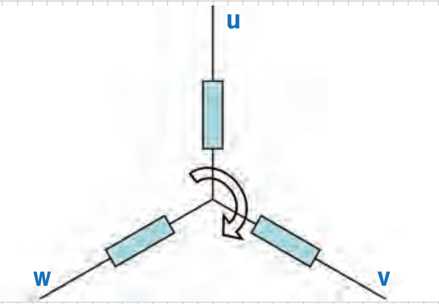
Due to the phase offset, the three-phase motor does not require the auxiliary phase that the alternating-current motor requires. The rotary field acting around the stator carries the rotor along, which means that the speed depends on the number of poles and the frequency (see alternating-current motor).

In hybrid technology, the speed of the three-phase motor is controlled by variations in the frequency. The frequency range that the power electronics require therefore depends on the number of pole pairs on the stator as a fixed variable and the maximum speed of the combustion engine, possibly in conjunction with an increase or reduction in the gear ratio. The phase sequence u, v, w indicates the rotational direction of a three-phase motor. If phases 2 and 3 are exchanged, the direction of rotation is reversed (see illustrations, star –> clockwise, delta –> counter-clockwise).

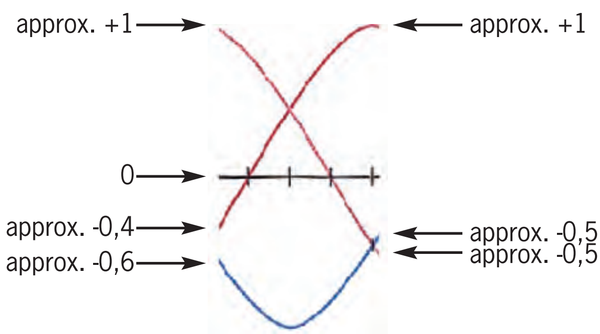
There are always two variations for switching all six coil connections on a three-phase motor (star or delta connection). The availability of two versions means that only three cables need to be routed to the motor or generator:

Star connection:

The addition of the three voltages u, v, w in the voltage/time diagram shows that the sum of the three voltages equals zero at all times.



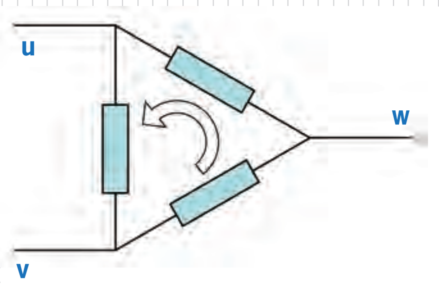
Star connection



One side of all coils can therefore be short-circuited as a star point. The individual coils are connected to a voltage that corresponds to the respective distance in relation to the zero line.

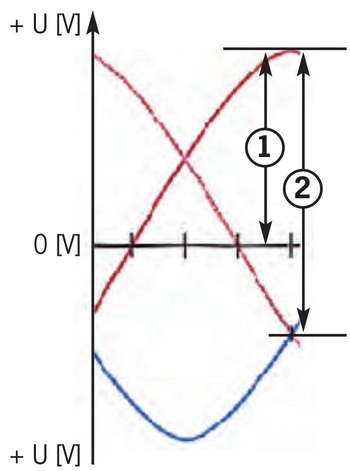
Delta connection:

The coils on a delta circuit are connected in series. Each coil is therefore connected to a voltage that corresponds to the respective distance of two phases.



Delta connection

The voltage/time diagram shows that the voltages are much higher than those of a star connection.

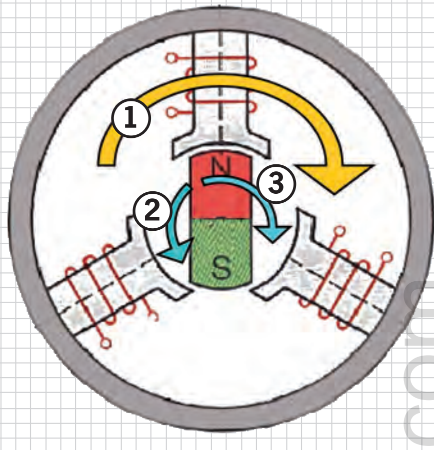


Voltage/Time diagram
1 Coil voltage, star connection
2 Coil voltage, delta connection

As a result, the currents and voltages from motors/generators with a delta connection increase by a factor of 1.73 (square root of 3) compared to the star connection. Power levels increase threefold with a delta connection. Coils used in Porsche hybrid modules are always connected in a delta configuration.

Asynchronous motors

The most common motors of all are asynchronous motors that use alternating-current or three-phase technology. Alternating-current capacitor motors, which have already been mentioned, also belong to this group. An extremely simple design and easy operation are two of the main advantages of this type of motor.



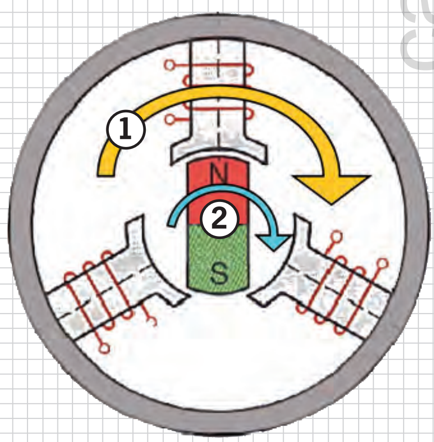
1 Rotary field speed
2 Speed difference, slip
3 Lower rotor speed

The term "asynchronous" refers to the difference between the speed of the rotary field and the speed of the rotor. Both speeds are asynchronous to one another. The greater the mechanical load on the motor shaft, the greater the speed difference (slip in %) and the amount of power consumed by the motor coils. The asynchronous motor would not generate any torque without this difference in speed. At the same time, this explains the high starting current. The performance ranges of asynchronous motors extend from small alternating-current motors in model railways to industrial motors operating in the megawatt range.

The two main disadvantages of asynchronous motors are the high starting currents and poor suitability as a generator for hybrid technology.

Synchronous motors

So-called synchronous motors are the most suitable motors for hybrid applications. In contrast to asynchronous motors, the impeller/rotor speed of synchronous motors is identical to the rotary field speed. This is achieved through a slight modification in the coil design and the position of the magnetic poles. The rotor speed is determined exclusively by the number of pole pairs and the frequency (slip =0).



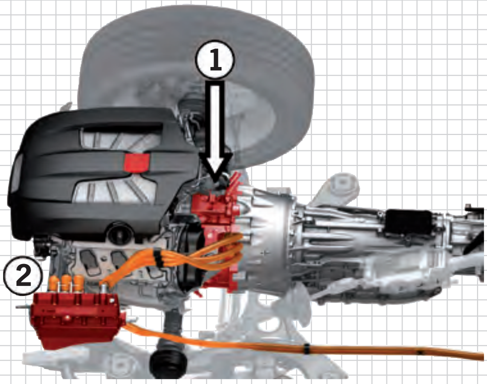
1 Rotary field speed
2 Rotor speed

The disadvantage of synchronous motors is their low resistance to overloading. If the mechanical load is too high, the rotor speed falls below the rotary field speed. As a consequence, the motor falls out of synchronization and stops. Therefore, a synchronous motor does not start autonomously.

The engine control has to compensate for this behaviour. In the Porsche Cayenne S Hybrid, the power electronics adapt the frequency accordingly. The frequency is increased from 0 Hz to the required speed in order that the motor can start. Consequently, a synchronous motor cannot operate without control electronics.

The advantages of the synchronous motor include the extremely compact design and simultaneous use as a generator. The illustration shows the complete hybrid module on the Porsche Cayenne S Hybrid, consisting of a dry clutch and electric motor/generator between the combustion engine and transmission. The complete module is almost 150 mm in length and generates a total electrical power of 38 kW.

The three-phase alternators used in Porsche vehicles are also synchronous generators!



1 Hybrid module
2 Power electronics

Power and work

The electric power (P=power) is defined as the product of current and voltage (P=U x I) and is measured in watts (W) or alternatively in kilowatts (kW). The nickel-metal hydride battery in the Porsche Cayenne S Hybrid generates a maximum electric power of 38 kW with a DC voltage of 288 volts. On this basis, the calculated maximum continuous current is I=131.9 A.

A higher current consumption is possible for a short time. A maximum pulse current of +120 A (charging) or -180 A (discharging) is specified. The battery manager is responsible for monitoring the battery. This control unit is part of the Battery Management System (BMS) and is located directly on the high-voltage battery in the rear of the vehicle.

Electric power (P) that is output or consumed over a certain period of time (t) is known as electric work (W=Work). The electric work W is therefore the product of power and time (W = P x t) and is recognized as an energy value because it represents the quantity of available energy.

With 12-volt batteries, the electrical capacity C in ampere hours (Ah) is usually specified and not the electric work W in watt hours (Wh) or kilowatt hours (kWh). The meaning is the same, however. Multiplying the battery voltage by the electrical capacity produces the electric work (W = C x t).

For comparison:
The 12-volt AGM battery installed in the Porsche Cayenne S Hybrid has an electrical capacity of 80 ampere hours (Ah) at 12 volts.

The resulting electric work or energy content value is:
960 watt hours (Wh), i.e. approx. 1 kWh at a nominal voltage of 12 V.
The high-voltage nickel-metal hydride battery installed in the rear of the vehicle has a total energy content of **approx. 1.7 kWh at a nominal voltage of 288 V.**
The specified power is **38 kW and the capacity is approx. 5.5 Ah.**

Efficiency
The efficiency refers to the ratio between the power output and the power consumed. One of the main arguments in favor of electric drives is the high degree of efficiency of all components.

While one can assume that the degree of efficiency of a combustion engine does not exceed 50 %, the efficiency of electric motors, electric generators and batteries can be as high as 90 %!

Voltage conversion
Different voltages used on the vehicle electrical system and electric drive must be converted to perform the following tasks:
- Three-phase current supplied by the generator converted into a direct current for charging the high-voltage battery via the pulse inverter or supplying power to the high-voltage air-conditioning compressor
- Direct current from the high-voltage battery converted into lower direct current for the 12 V vehicle electrical system
- Direct current from the high-voltage battery converted into three-phase current for the electric power train (phase inverter)
- If a 12-volt charger is used to charge the high-voltage battery, the voltage must be converted here as well. This variation is not available for the Porsche hybrid concept. However, an external high-voltage charger is available for charging the high-voltage battery.

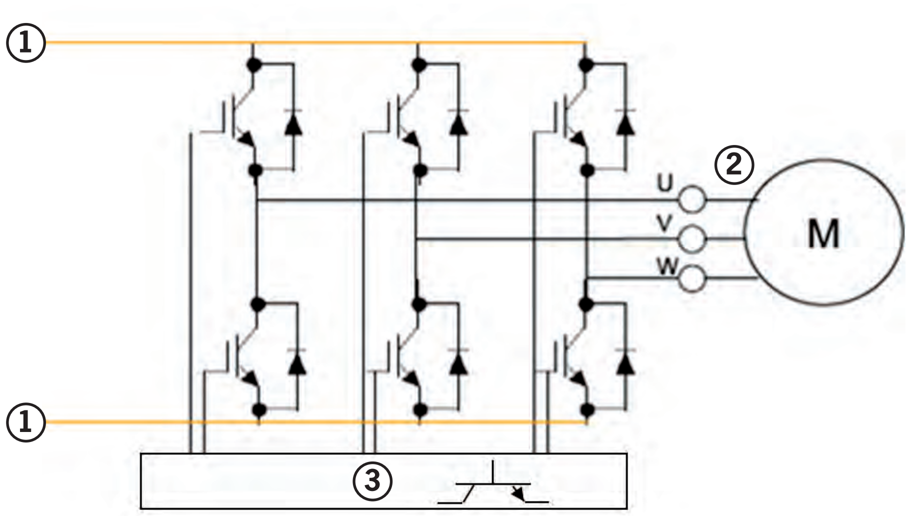
!

The vehicle cannot operate if the 12 V battery is discharged because the 12 V vehicle electrical system supplies voltage to the control units.
In this case, the battery is charged in the conventional way.

Pulse inverter

A direct current is converted into a three-phase alternating current and vice versa using a circuit known as a buck or boost converter.

When combined, these two converters are known as a pulse inverter.



Pulse inverter
1 Direct-current connections
2 Three-phase alternating current
3 Microprocessor control

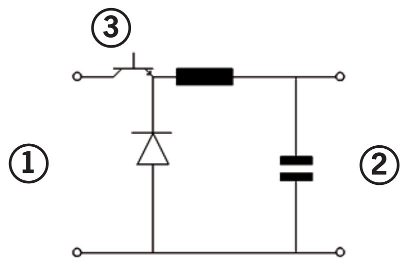
While the top circuit (boost converter) is responsible for positive alternation, the bottom circuit (buck converter) generates the negative alternation. A microprocessor activates the transistors several times per second. Almost any frequency or voltage level can be generated at the output. If the electric motor functions as a generator, the circuit converts the three-phase alternating current into the required direct current, which is then used to charge the high voltage battery or supply power to the high-voltage air-conditioning compressor.

DC/DC conversion

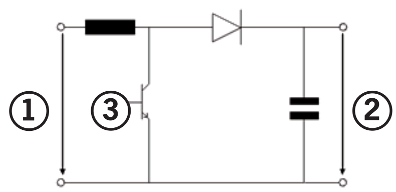
While the voltage level of alternating currents can be modified quite easily using a transformer, direct currents are converted using basic circuits consisting of a coil, a diode and capacitor.

Circuits used:

Buck converter –> Decreases the direct current



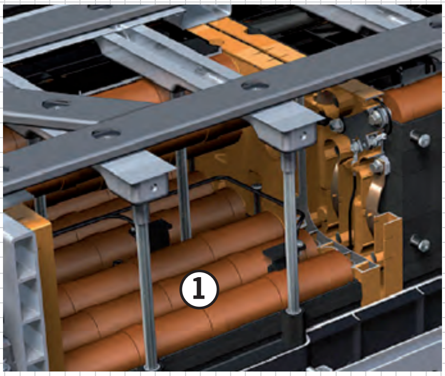
Boost converter –> Increases the direct current (not included in the Porsche hybrid concept)



DC/DC conversion
1 Input voltage
2 Output voltage
3 Activation (ground side)

A transistor (switch) switches the circuits on and off in quick succession. The duty cycle of these switching processes determines the extent to which the voltage is increased or decreased.

The DC/DC converter and the pulse inverter are the two main components in the power electronics. The rapid switching of the power transistors generates heat that must be dissipated by a coolant system. A separate low-temperature circuit that operates alongside the charge-air cooling system inside the air charging module on the 3.0 l V6 DFI engine is responsible for cooling the power transistors.



Internal design of the high-voltage nickel-metal hydride battery in the Porsche Cayenne S Hybrid

1 Individual battery cell

High-voltage batteries

Introduction

At present, there are no satisfactory solutions available for the storage of large quantities of electrical energy. While only capacitors offer the possibility of direct storage, all batteries store electricity in the form of chemical energy. Storing energy in a battery is currently more practical that a capacitor storage option and only very limited quantities of electricity can be stored in "Supercaps" (super capacitors). The voltage of an individual battery cell has a chemical base and does not exceed 2 volts. In all high-voltage batteries, several cells are therefore connected in series in order to achieve higher voltages. In the high-voltage battery on the Cayenne S Hybrid, modules of six cells are connected in series (7.2 V). 40 of these modules are in turn connected in series and generate a total voltage of 288 V.

The energy density, which is specified in watt hours per kilogram (Wh/kg), is decisive for determining the suitability of a storage medium.

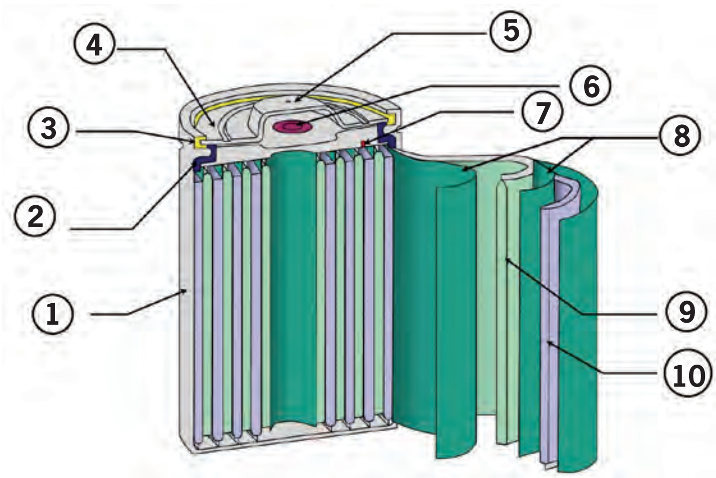
The higher the specified value, the lighter (smaller) the storage medium is, while containing the same quantity of energy. Capacitor technology can currently achieve a maximum energy density of 10 Wh/kg.

Standard batteries such as the high-voltage nickel-metal hydride battery in the Porsche Cayenne S Hybrid can achieve an energy density of approx. 80 Wh/kg. Capacitors do not yet present a viable option for long-term energy storage because of their relatively high degree of self-discharge.

For comparison:
The energy density of gasoline is 12,000 Wh/kg!

Nickel-metal hydride batteries

The source voltage of a single cell on an NiMH battery is generated by an excess of charged hydrogen particles on an electrode. A nickel-oxygen-hydrogen compound (nickel hydroxide) is used as a positive electrode. The negative electrode consists of a metal alloy that can store hydrogen reversibly.



Structure of an NiMH cell

1 Housing and connection
2 Insulation
3 Seal
4 Cover
5 + connection
6 Safety valve
7 PTC (temp. dependent resistance)
8 Separator
9 Positive electrode
10 Negative electrode

During the charging process, hydrogen particles migrate from the negative electrode to the positive electrode and attach themselves to the electrode material. The discharge process is identical, but runs in reverse.

An NiMH cell incorporates two safety mechanisms. A PTC resistor restricts the current flow at high temperatures and a safety valve releases excess pressure generated in the cell in a controlled manner.

Nickel-metal hydride batteries have replaced previously common nickel-cadmium batteries. Of the three basic cell designs for battery systems (flat cell, round/cylindrical cell and prism cell), Porsche uses the cylindrical cell because it has extremely stable mechanical properties, a high energy density and is cheap to manufacture. In addition, cylindrical cells are easier to cool because of the spaces between the cells. The energy density of a nickel-metal hydride battery is typically 80 Wh/kg. Higher energy densities are not expected in the near future.

Li-ion batteries

On a lithium-ion battery, the source voltage of the individual cells is generated through the migration of positively charged lithium atoms (=lithium ions). The material used for the positive electrode is lithium oxide (lithium-oxygen compound) and graphite is often used for the negative electrode.

During the charging process, positive lithium ions migrate from the positive electrode to the graphite layers on the negative electrode, which generates an excess charge that can be measured as a source voltage in the individual cell. The discharge process is identical, but runs in reverse.

Lithium is volatile and reacts with other materials much more readily than nickel. Although the energy density of a lithium-ion battery is significantly higher (approx. 150 Wh/kg), costly internal safety measures are required to protect the battery from exhaustive discharge, for example. In the initial development phase, isolated problems occurred in consumer electronics because insufficient protective measures were taken.

Lithium-ion batteries currently enjoy widespread use in consumer electronics. An advanced stage of development, superior safety measures and lower costs clearly make the nickel-metal hydride battery the better choice as a high-voltage energy store for hybrid technology.

!

Exhaustive discharge followed by a complete recharge for “regeneration“ is only possible and appropriate with nickel cadmium batteries.

Both types of battery described are extremely sensitive to overload and exhaustive discharge and the chemical processes that occur in the cells are irreversible. Conductive connections that can cause the battery to overheat also occur during exhaustive discharge of a lithium-ion battery (see above). The available overall capacity of the nickel-metal hydride battery decreases every time a charge/discharging process exceeds certain limits. For this reason, it is usual for the battery management system to limit the used bandwidth of the overall energy content. The battery ages in very small stages that are not perceptible for the driver. The high-voltage battery in the Porsche hybrid drive is designed to last for the vehicle lifetime.

Batteries reach maximum power within a defined temperature range. On the high-voltage battery used in the Porsche Cayenne S Hybrid, this range is between +50° F. (10° C.) and +99° F. (37° C.). The installation position of the battery provides protection against excessively low temperatures. A pulse charge/discharge can be actively applied to the high-voltage battery to help the battery reach the perfect operating temperature. An air-cooling system protects the battery from excessive temperatures.

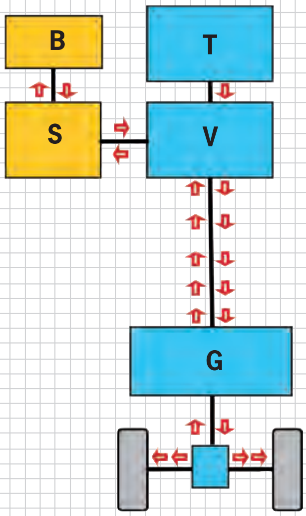
Hybrid variants

A hybrid drive is a combination of two different power units that operate according to different functional principles. At present, the universal meaning of the term "hybrid technology" is the combination of a combustion engine and an electric drive. A distinction is made between three types of hybrid drive, depending on the basic design:

- the micro hybrid drive,
- the mild hybrid drive,
- the full hybrid drive.

Hybrid types (performance range)	**Micro hybrid** (approx. 2-10 kW)	**Mild hybrid** (approx. 15-30 kW)	**Full hybrid** (approx. 20-75 kW)
Functions			
Start/Stop	X	X	X
Regenerative braking	X	X	X
Boosting		X	X
Driving under electric power			X
Customer benefits			
Reduced fuel consumption	X	X	X
Driving dynamics		X	X
Driving under electric power			X

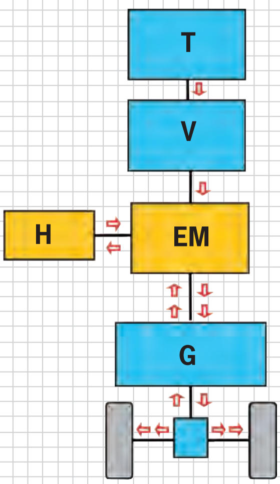
Examples of all variants are available on the market from different manufacturers. Only the full hybrid can benefit from all the advantages of the combustion engine and electric motor combined. The technology Porsche uses in the single-shaft parallel full hybrid is state-of-the art hybrid drive technology and currently achieves the best performance possible.



T Fuel tank
V Combustion engine
G Transmission
S Starter
B 12-volt battery

The micro hybrid drive

In this drive concept, the electric component (electric starter/generator) is only used to activate the start/stop function. During braking, part of the kinetic energy is converted back into electrical energy (recuperation). However, it is not possible to drive on electric power alone. The characteristics of the starter and the 12-volt battery have been adapted to cater for frequent engine starts.



T Fuel tank
V Combustion engine
EM E-machine
G Transmission
H High-voltage battery

The mild hybrid drive

The electric drive assists the combustion engine and so the high-voltage battery is also referred to as a traction battery. However, it is not possible to drive on electric power alone. On the mild hybrid drive, a substantial proportion of the kinetic energy generated during braking is recovered and stored in the high-voltage battery in the form of electrical energy. The high-voltage battery and the electrical components are designed for higher voltages and therefore higher levels of power. A 12-volt battery and a conventional starter can be installed in addition to the high-voltage battery. With assistance from the E-machine, the driver can benefit from an additional boost torque.

The full hybrid drive

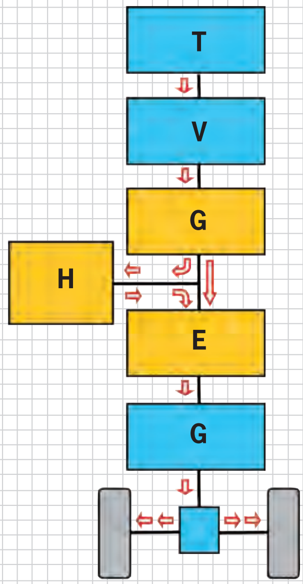
A powerful electric motor is combined with a combustion engine. Driving solely under electric power is possible and the vehicle range only depends on the size of the high-voltage battery (traction battery). The electric motor assists the combustion engine when required via a torque request from the driver. On low speed trips, the vehicle can drive solely under electric power. The combustion engine is switched off when no longer required and the hybrid management system decides when the combustion engine needs to be switched back on again. Recuperation (recovery of brake energy) is used to charge the high-voltage batteries.

Full hybrid drives fall into three categories:

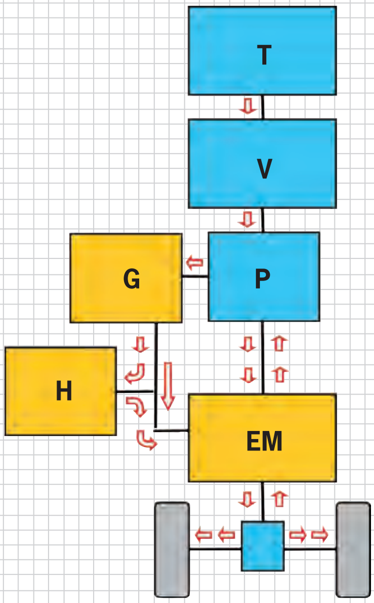
- Serial hybrid drives
- Power-split hybrid drives
- Parallel hybrid drives

The serial hybrid drive

A similar version of this drive variant has been used for years in drives on electric diesel locomotives and ships, for example. There is no connection between the combustion engine and the wheel and so the E-machine powers the vehicle. The combustion motor can always be operated in the best operating range and generates mechanical energy for the generator. Power is supplied to the electric motor either directly from the generator or from the high-voltage battery. If the capacity of the high-voltage battery is too low, the combustion engine starts and charges the high-voltage battery via the generator.



T Fuel tank
V Combustion engine
G Generator
E Electric motor
G Transmission
H High-voltage battery



T Fuel tank
V Combustion engine
P Planetary transmission
EM Electric motor
G Generator
H High-voltage battery

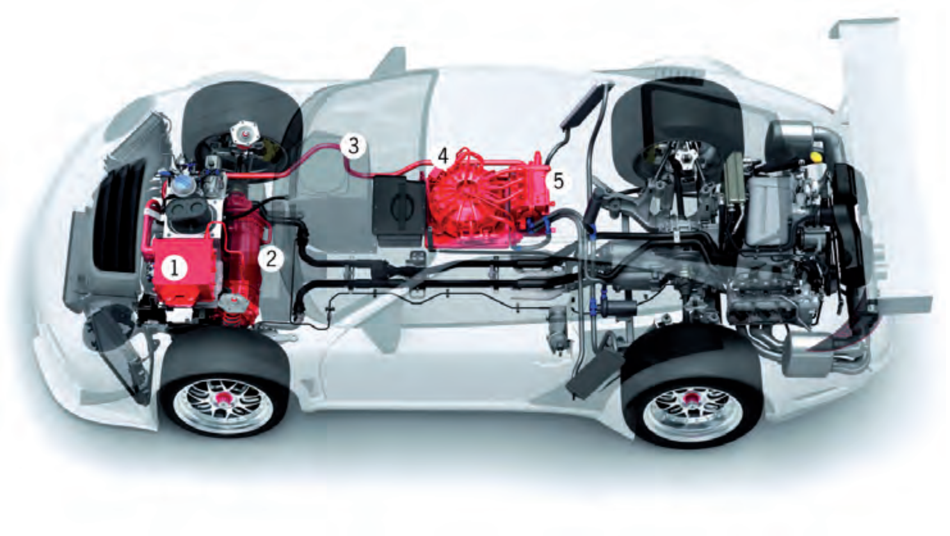
The power-split hybrid drive

In addition to a combustion engine, the power-split hybrid drive also has a generator and an electric motor. All are located on the front axle. The vehicle is powered by the combustion engine via a planetary transmission or simultaneously via the E-machine on the vehicle transmission. Serial or parallel operating mode can be selected, depending on the whether or not the planetary transmission is activated. In contrast to the parallel hybrid system, the sum of the individual power sources of the two drive types cannot be applied to the wheel. In order for the vehicle to drive, part of the power supplied by the combustion engine is always converted into electrical energy by the generator and released to the wheels via the E-machine. The maximum drive power is the sum of the power from the combustion engine and the battery.

The power-split serial hybrid drive

A combination of the previously mentioned drive variants can be used on all-drive vehicles. The power-split serial hybrid drive has a combustion engine and two E-machines. The second E-machine can be activated to power the front axle whenever necessary.

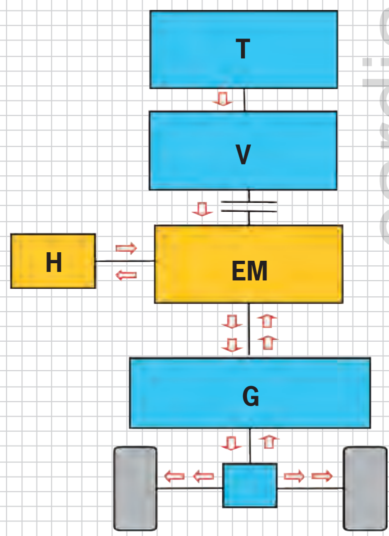
Porsche has adopted this drive concept from near-series vehicles in GT motor sport. Two E-machines that generate a total of 120 kW and the powerful 480 hp Boxer engine in the rear power the front axle of the new Porsche 911 GT3 R. An flywheel accummulator generator/motor is used instead of a conventional high-voltage battery. The two E-machines generate electrical energy during braking, which is then converted into rotational energy in the flywheel accumulator. During overtaking manoeuvres or when accelerating out of bends, the flywheel accumulator assumes the function of a generator and powers the two E-machines on the front axle.



1 Power electronics 1
2 Two electric motors
3 High-voltage cable
4 Flywheel accumulator
5 Power electronics 2

The parallel hybrid drive

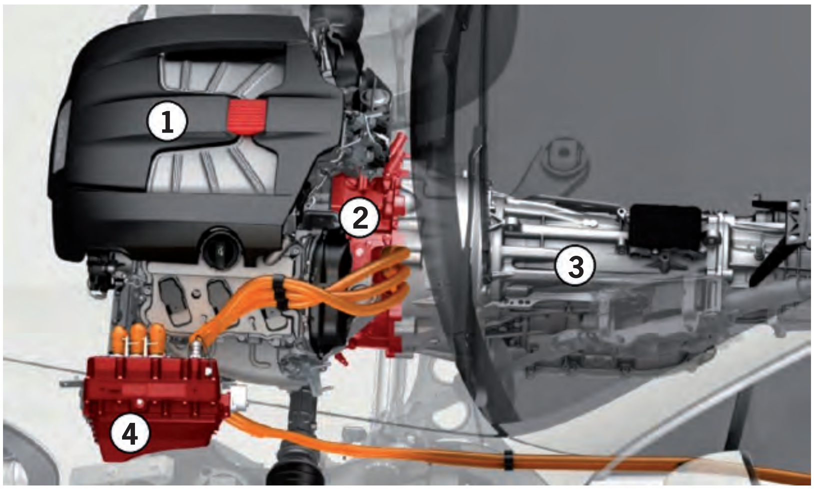
This drive is often used when an existing vehicle is "hybridized" and is characterized by the simplicity of the parallel design. Most existing parts can be integrated without having to be redesigned. This is also facilitated by the small installation dimensions of the hybrid module, which has a compact size of only approx. 15 cm in the Cayenne S Hybrid.



T Fuel tank
V Combustion engine
P Planetary transmission
EM E-machine
G Transmission
H High-voltage battery

The Porsche Cayenne S Hybrid uses a single-shaft parallel hybrid drive concept.

The hybrid module is located on a single shaft between the combustion engine and the drive train and is only approximately 15 cm in length. A decoupler is integrated in the hybrid module so that the hybrid management system can interrupt the power transmission between the combustion engine and the E-machine.



1 Combustion engine
2 Hybrid module with decoupler
3 Transmission
4 Power electronics

The Porsche parallel hybrid drive concept allows for a total of six different hybrid-specific driving modes which the hybrid manager integrated in the Bosch MED 17.1.6 engine control unit selects in line with the relevant driving scenario:

1) Driving exclusively under electric power
   - The decoupler is opened and the combustion engine is switched off. The E-machine is the only motor powering the vehicle.

2) Boosting
   - The decoupler is closed, the combustion engine and the E-machine (as a motor) power the vehicle. The torques and power are combined to produce the total output.

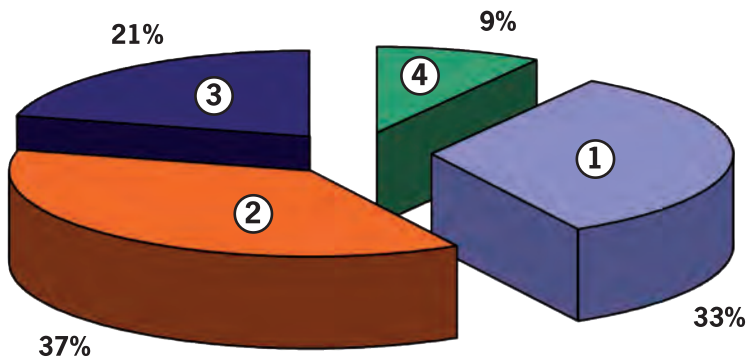
3) Combustion engine powered driving with load point shift
   — Option 1: The decoupler is closed, the combustion engine charges the battery and powers the vehicle (load point increase).
   — Option 2: The decoupler is closed, the combustion engine powers the vehicle with assistance from the E-machine (load point decrease).

4) Coasting (unpowered gliding up to 97 mph/156 km/h)
   - The decoupler is open and the combustion engine is switched off. The E-machine operates almost entirely without friction. The vehicle rolls without significant braking torque.

5) Regenerative braking (recuperation)
   - The E-machine generates current (as a generator) that is used to charge the high-voltage battery and operate the vehicle electrical system.

6) Auto Start Stop function
   - The hybrid management system is exclusively responsible for starting and stopping the combustion engine. The driver cannot have a direct influence here.

In the New European Driving Cycle (NEDC), the driving modes are divided as shown in the diagram below.



1 Combustion engine stop
2 Combustion engine start
3 Driving under electric power
4 Recuperation

The NEDC Driving Cycle does not take into consideration the "boosting" and "coasting" operating modes.

Drive train

Hybrid-specific adaptations

Omission of components

It was possible to omit two auxiliary units as a result of the hybridization:

- A conventional starter is not used. The E-machine starts the vehicle after the decoupler is actuated.
- Omission of 12 V generator. The DC/DC converter from the power electronics converts the voltage from the high-voltage battery to a suitable level for powering the vehicle electrical system.

Electric auxiliary systems

In order to assist various vehicle functions when the combustion engine is switched off, individual components have been changed to electrical components and some electrical components have been added:

- Electric high-voltage A/C compressor for cabin air conditioning
- Electro-hydraulic servo pump for power steering
- Electric auxiliary vacuum pump for brake power boost
- Electric auxiliary oil pressure pump for transmission oil supply
- Two electric auxiliary water pumps (one for the high-temperature circuit and one for the low-temperature circuit)
- Electro-hydraulic spindle actuator for actuating the decoupler

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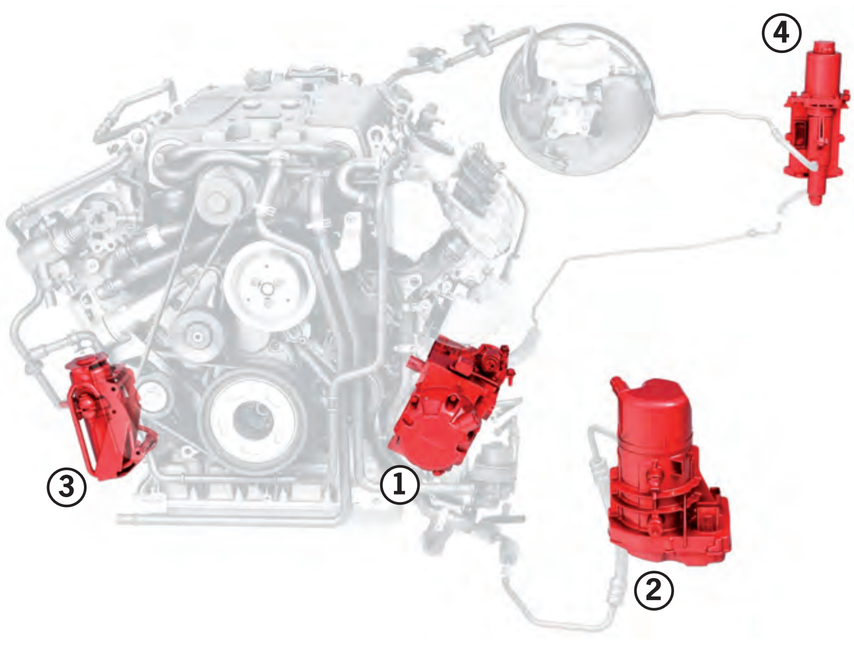
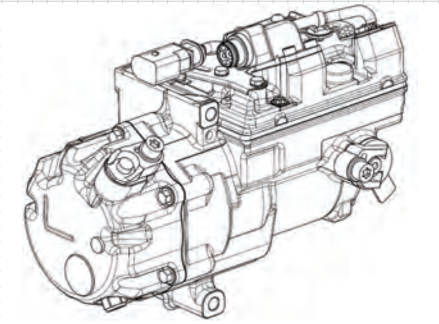
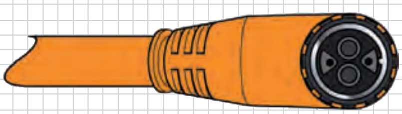
See the chapters "Combustion engine", "Power transmission" and "Chassis" for further information.



1 High-voltage air-conditioning compressor
2 Servo pump (power assistance)
3 Vacuum pump (brake boosting)
4 Spindle actuator (decoupler)

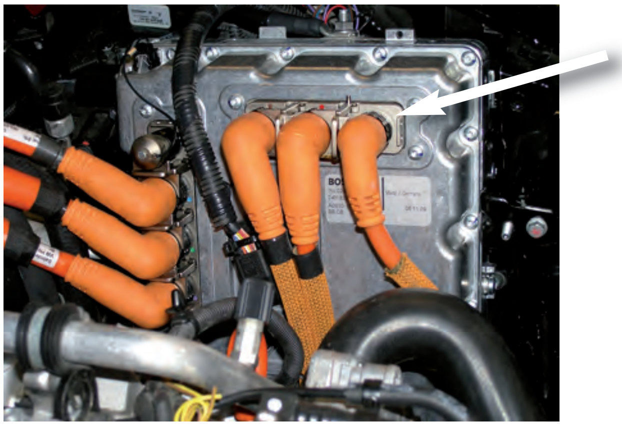




See "Air conditioning" assembly for further information.

Air-conditioning compressor

As a consumer with maximum power requirements of 3.2 kW, the air-conditioning compressor was connected to the 288 V NiMH battery power supply. The power electronics supply a DC voltage from the battery to the air-conditioning compressor via a high-voltage cable. A fuse for the air-conditioning compressor is integrated in the power electronics.

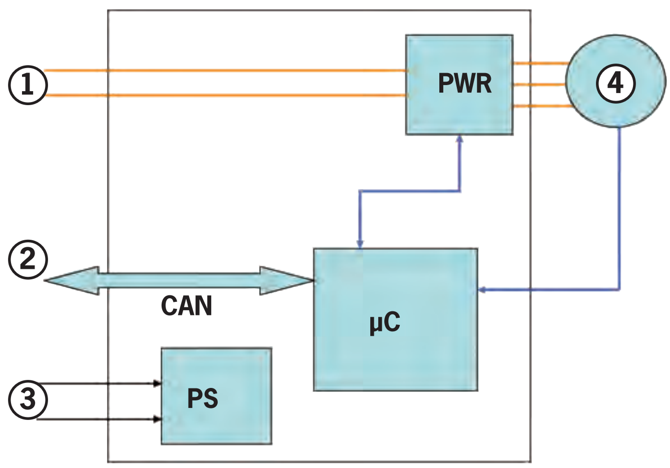


While all remaining connections to the power electronics are single-wire cables, the connecting line to the air-conditioning compressor incorporates four wires, two poles for the direct current supply and two pilot lines to safeguard the integrity of the overall system.

The motor on the air-conditioning compressor is a three-phase motor (brushless direct current motor). The direct current is converted to a three-phase alternating current of 3 x 280 volts on the air-conditioning compressor.

Block diagram
High-voltage air-conditioning compressor control

1	288 V DC
2	CAN connection (airbag control unit)
3	Term. 15 and 31
4	Three-phase motor
PS	Internal power supply unit
PWR	Pulse inverter
µC	Control unit
(blue arrow)	Information
(orange line)	High-voltage line



Other auxiliary units

The power-steering pump is also energized with a nominal voltage 12 V DC to safeguard power assistance while the combustion engine is off.

The additional electrical oil pressure pump for supplying oil to the transmission ensures that a sufficient quantity of oil flows to all moving parts and that the gear can still be changed even when the combustion engine is switched off.

Electrically powered pump units enable the brake and power assistance system to function when driving solely under electric power, for example.

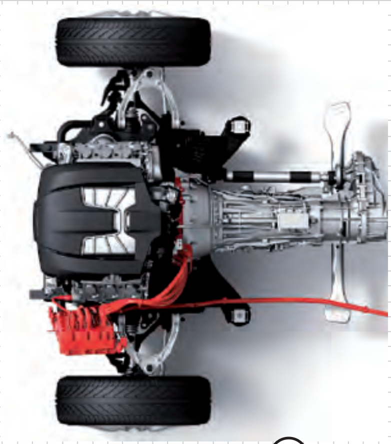
The cooling of powerful components from the hybrid drive train such as the electric motor and the power electronics must continue when the combustion engine is switched off. Two electric coolant pumps are used for this.

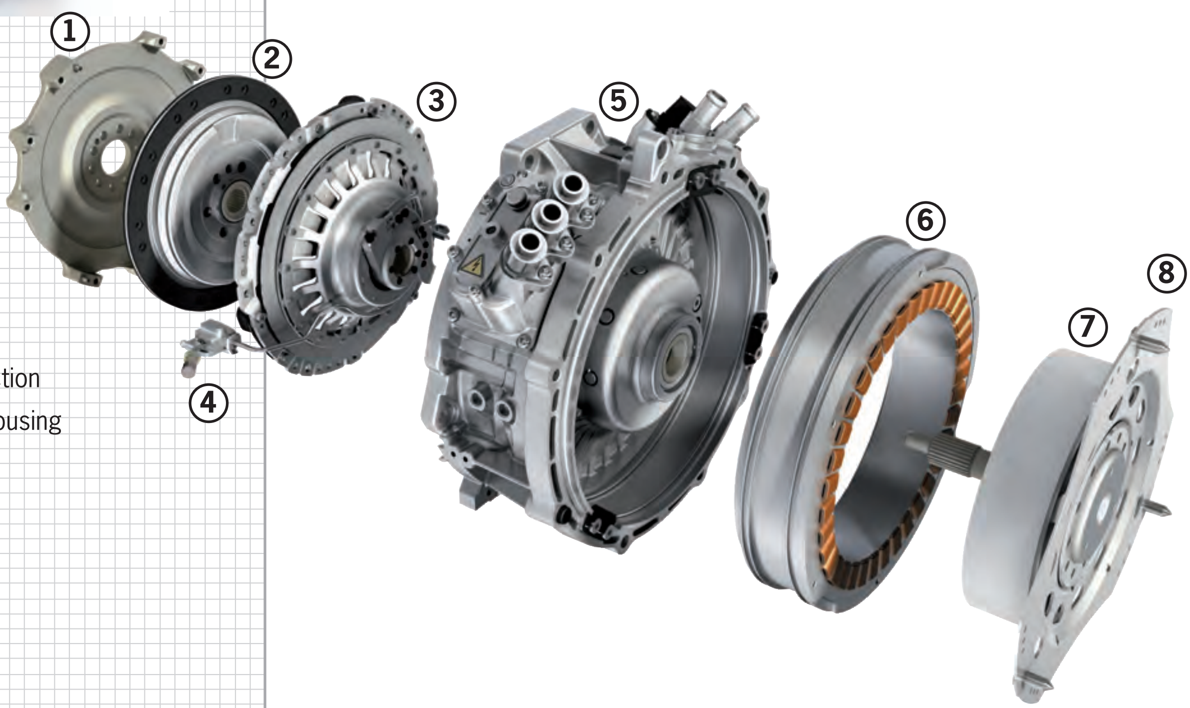
!

See the relevant assemblies for further information.

Hybrid module

The hybrid module is integrated between the combustion engine and the transmission according to the modular principle. The complete module consisting of E-machine and clutch is only 147.5 mm in length and weighs approx. 117 lbs (53 kg). Due to its compact dimensions, it was possible to integrate the module in the drive train without making major modifications.





1 Flywheel
2 Drive plate
3 Pressure plate
4 Hydraulic connection
5 Hybrid module housing
6 Stator
7 Rotor
8 Flex plate

!

A special tool is required to install and remove the hybrid module and individual components. When performing work, do not damage or bend the hydraulic line under any circumstances. See Workshop Manual!

The module consists of a decoupler at the end connected to the combustion engine and the E-machine, which transmits power to the transmission via the flex plate. The rotor on the electric motor with flex plate connects the hybrid module at the transmission end to the converter on the 8 speed automatic transmission. While the components on the electric motor can only be replaced as a complete unit, the components on the decoupler, flywheel, drive plate and pressure plate can be replaced individually.

Decoupler

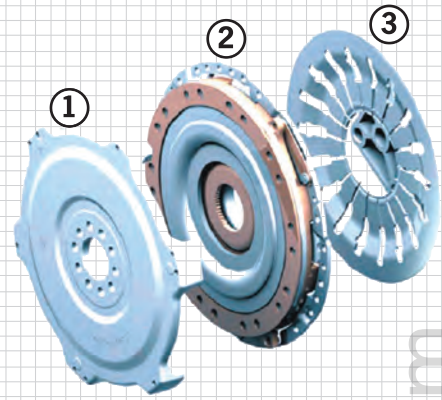
The decoupler transmits the power from the combustion engine to the hybrid module and enables rapid, smooth coupling and decoupling when the transition is made between hybrid-specific operating modes. During the transition from electric motor mode to combustion engine mode, the decoupler closes rapidly within approx. 70 ms with a high degree of torque accuracy.

The decoupler is closed in all operating modes where power is transmitted between the combustion engine and the drive train. It makes sure that power from the combustion engine is transferred rapidly to the E-machine, transmission and then to the road without affecting driving comfort.
The following requirements apply to the decoupler:

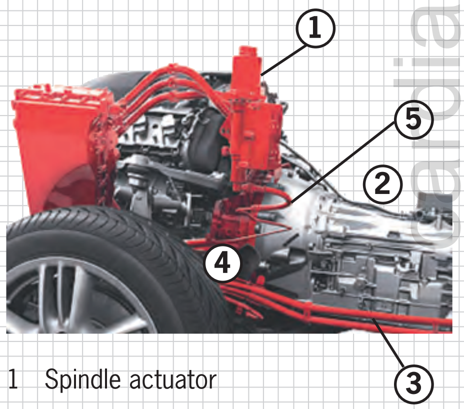
- Engine torque transferred with a high degree of accuracy
- Outstanding driving comfort
- High degree of reliability
- Guarantee that drag torque is not generated when the decoupler is open and the vehicle is driving under electric power
- Extremely solid

The decoupler is a dry clutch consisting of a flywheel, drive plate and pressure plate. The flywheel establishes the connection to the hybrid module at the engine side and reduces fluctuations in speed through mass inertia.

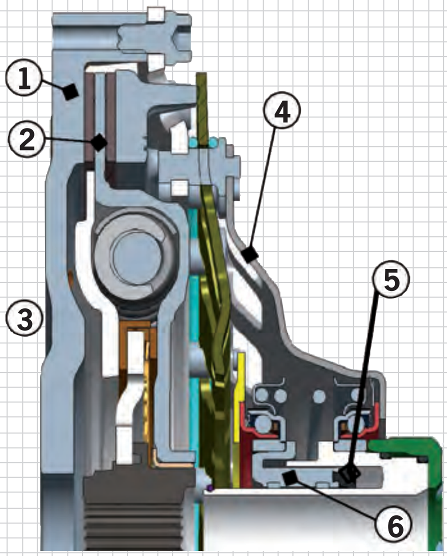
Furthermore, an arc spring damper that dampens torsional vibrations in a similar way to a dual-mass flywheel is installed in the clutch. The secondary mass is made up of the rotor on the E-machine and the pump wheel of the torque converter.



1 Flywheel
2 Drive plate
3 Pressure plate



1 Spindle actuator
2 Transmission
3 High-voltage lines
4 Hybrid module
5 Hydraulic line to the hybrid module



The connection for the hydraulic line to the spindle actuator (hydraulic control unit) is attached to the pressure plate on the decoupler. The spindle actuator hydraulically controls the central release module to open and close the decoupler.

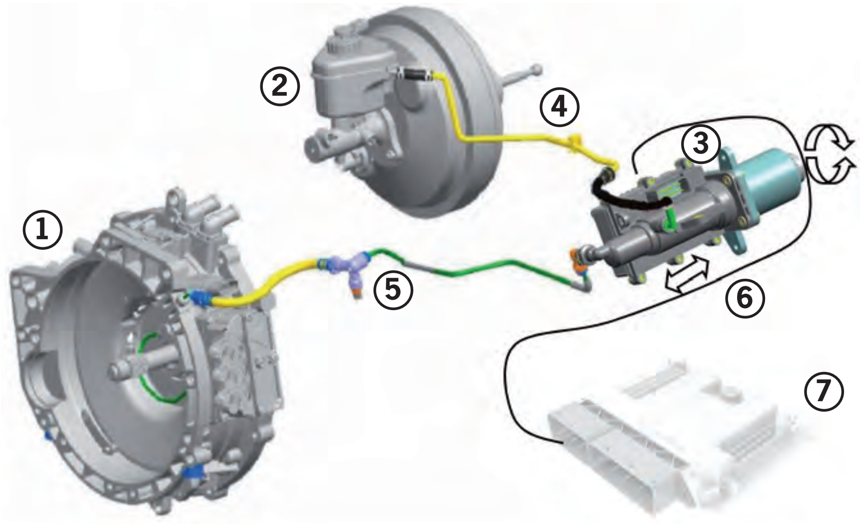
During the engaging process, the force of the cup spring on the pressure plate (4) pushes the drive plate (2) against the flywheel (1) and power is transmitted.

1 - Flywheel	4 - Pressure plate
2 - Drive plate	5 - Hydraulic pressure chamber
3 - Combustion engine side	6 - Actuator piston Open <– –> Close

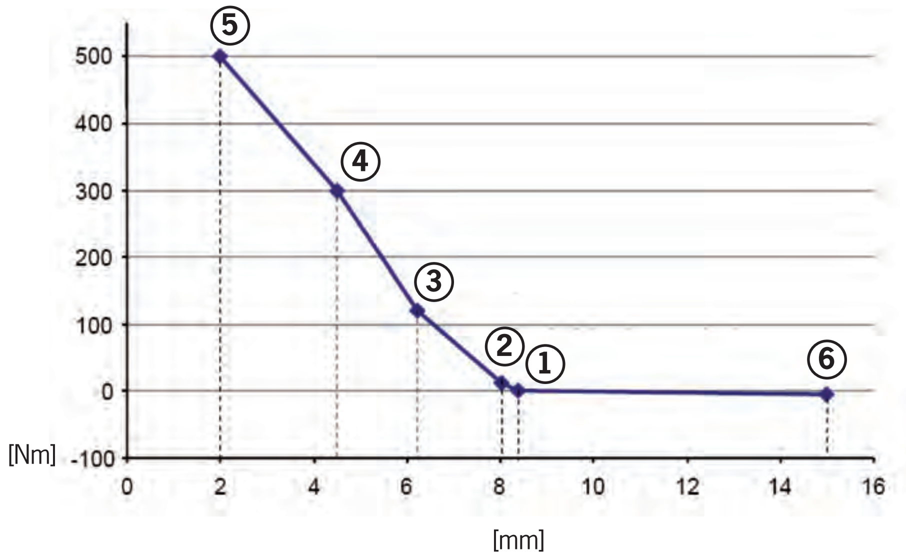
Function

The hybrid manager integrated in the housing of the DME control unit Bosch MED 17.1.6 controls the spindle actuator via the CAN Hybrid bus depending on the prevailing driving situation, thereby allowing continuous changes between the different hybrid-specific driving modes.

A ball thread spindle in the spindle actuator converts the rotation motion of the electric servo motor into a translation movement in the master cylinder. The system is supplied with hydraulic fluid from the brake fluid expansion tank.



1 Hybrid module housing
2 Brake fluid expansion tank
3 Spindle actuator with control unit (CCU)
4 Return line
5 Pressure line to hybrid module
6 Activation via CAN Hybrid
7 Hybrid manager in DME control unit Bosch MED 17.1.6



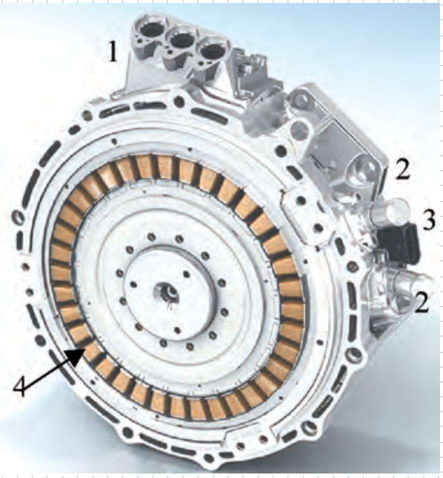
1 Physical sample point
2 New sample point calculated from adaptation
3 Start adaptations
4 Hybrid adaptations
5 Clutch fully closed
6 Clutch open

In the above diagram, the torque is specified in relation to the actuator adjustment travel. The clutch is actuated by the **Porsche Hybrid Clutch Management (PHCM)** system integrated in the hybrid manager.

The PHCM strategies are based on:

- Compensation (temperature, speed, etc.)
- Adaptation (aging, component range, wear, etc.)
- Diagnostics (slip, torques, dynamic response, etc.)
- Zero position (clearance, adjustment speed, preload, etc.)

The hydraulic system is bled and the basic settings configured by means of guided functions using the PIWIS Tester. The system also has diagnostic capabilities.



1 Three-phase connection
2 Coolant connections
3 Sensor connection
4 Stator coils

Electric motor

The 70 cm long cast aluminum housing on the hybrid module is located between the combustion engine and the automatic transmission. Three-phase current connections that link the module directly to the power electronics are located on the housing. Power is supplied to and drawn from the E-machine along these 288 V lines.

Purely electric driving is possible on a flat road up to approx. 30 mph (50 km/h), and speeds of up to approx. 37 mph (60 km/h) are possible in E-Power mode. Temperature sensors integrated in the stator coils monitor the temperature and send the measured values to the hybrid manager via the CAN bus. The relevant connection is located between the coolant connections.

The following table contains technical data relating to the electric motor.

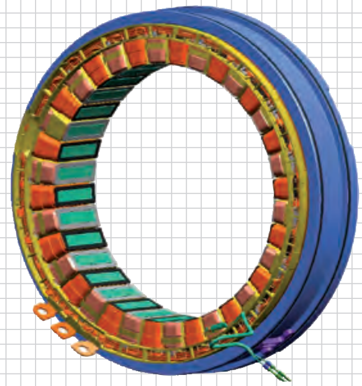
Feature	Value/Description
Engine type	Three-phase synchronous electric motor, inner rotor, brushless with permanent magnets
Cooling	Water cooling (integrated in high-temperature circuit)
Power	38 kW electrical/34 kW mechanical
Torque	285 (max. 300) Nm
Nominal voltage	288 V AC
Efficiency	Approx. 90 %
Dimensions	Stator diameter 300 mm, electric motor length 70 mm

Stator/Rotor

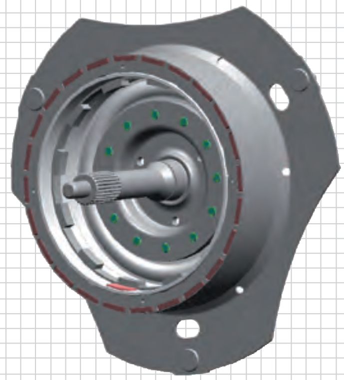
The stator is an external component of the electric motor that has 36 individual tooth coils made from copper wire and is secured in a defined position on the electric motor housing. The rotor position sensors fitted to the stator measure and transmit the current position of the rotor to the control unit in the power electronics. This data is then used to adjust the frequency to achieve the required speed and supply a three-phase alternating current to the coils.

Permanent magnets made from neodymium iron boron in the inner rotor generate a magnetic field. The rotor is fixed to the drive shaft and fitted to the stator in such a way as to enable a rotary movement. The flex plate secured to the back of the rotor establishes the connection to the transmission.

When the engine is operating, the electric motor generates a maximum of 38 kW of electric power at a voltage of 288 V, which is output with a specified efficiency degree of 90 % in the form of mechanical power amounting to approx. 34 kW. The E-machine delivers this power continuously across almost the entire engine speed range until just before the combustion engine reaches the speed limit. In Boost mode, the total power outputs of the combustion engine and electric machine are added, with the result that the power curve of the overall system has the characteristic of a combustion engine.



Stator

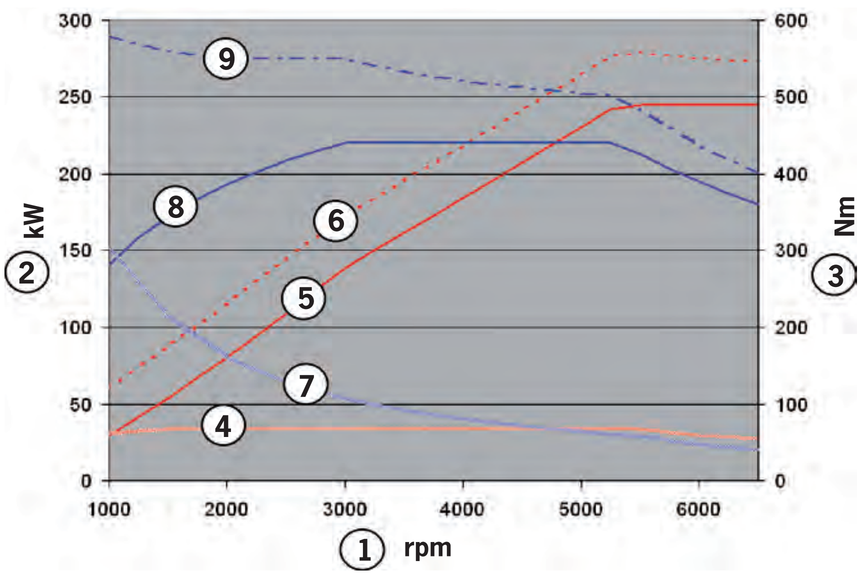


Rotor

Electric motors can reach maximum torque from a standing start. When combined with the combustion engine, electric motors provide an opportunity to improve power output, especially at low engine speeds.

- The maximum torque increases during boosting, which enhances driving off capabilities in particular.
- Operating alone, the electric motor can accelerate the vehicle from a standing start if the accelerator pedal is pressed gently.

Below engine speeds of 1,150 rpm, e.g. when driving off, the torque can be increased from 285 Nm to a maximum of 300 Nm for approx. 3 seconds (boosting).



Output graph for the Cayenne S Hybrid

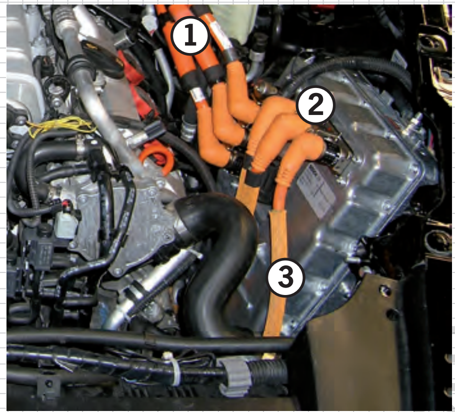
1 Engine speed
2 Power
3 Torque
4 E-machine power
5 Combustion engine power
6 Total power
7 E-machine torque
8 Combustion engine torque
9 Total system torque

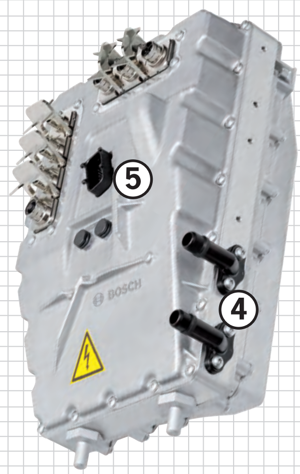
Power electronics

The power electronics are located in an aluminium housing at the front left of the engine compartment between the combustion engine and the wheel housing. The weight of the module is approx. 31 lbs (14 kg).

The power electronics incorporate various components:

- Pulse inverter (PWR) 288 V DC <– –> 288 V AC
- DC/DC converter, 288 volts –> 12 volts
- Control unit for power electronics
- High-voltage power distributor with fuse for the air-conditioning compressor





- Connections for:
  - Three-phase alternating current to E-machine (1)
  - Direct current (+ and -) to high-voltage battery in rear of vehicle (2)
  - High-voltage connection for air-conditioning compressor (3)
  - Coolant connections, low-temperature circuit (4)
  - Connection for hybrid control (5)
  - Low-voltage connections for the 12 V vehicle electrical system (+ potential at screw terminal at top left, ground at top of housing)
  - Connection for equipotential bonding (at right of housing, further information on equipotential bonding can be found in Group 9)

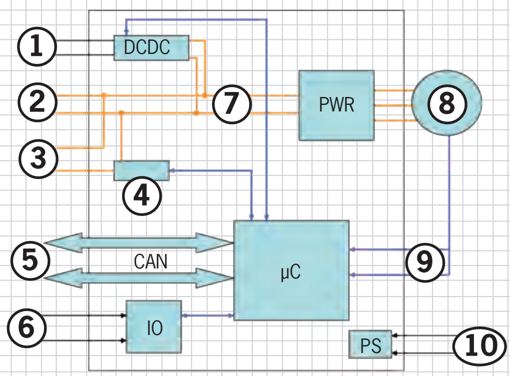
Pulse inverter (PWR)

The direct current from the traction battery must be converted into a three-phase alternating current before it can be used for propulsion in the electric motor. If the electric motor is in generator mode when energy is recuperated during braking, the alternating current generated is converted back into a direct current and then stored in the battery. The pulse inverter is responsible for these two tasks. A maximum of 370 A can be generated momentarily in electro-mechanical mode in contrast to currents between 100 A and 150 A that flow in normal mode.

DC/DC converter

The DC/DC converter reduces the direct current from the 288 V high-voltage battery to 12 volts so that power can be supplied to the auxiliary units and other consumers in the vehicle electrical system and the 12-volt battery can be charged.

The assembly is integrated in the low-temperature circuit of the combustion engine to dissipate the generated heat.



Block diagram for power electronics

1 - Terminal 30 and 31
2 - 288 V DC from the HV battery
3 - 288 V DC to air-conditioning compressor
4 - Fuse
5 - CAN Hybrid and CAN Drive
6 - Terminal 15 and 50
7 - 288 V DC
8 - E-machine
9 - Temperature and rotor position
10 - Terminal 15 and 30
µC - Control unit for power electronics
IO - Input/Output module
PS - Internal power supply unit

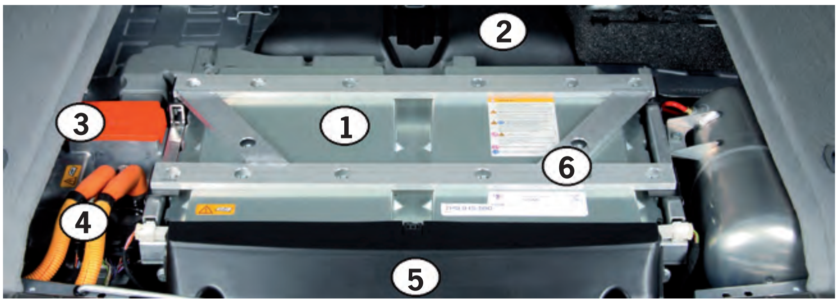
↔ Information
— High-voltage line

High-voltage battery

The low-cost nickel-metal hydride battery in the Cayenne S Hybrid uses established technology with impressive characteristics such as outstanding operating reliability and durability. The NiMH battery is housed above the rear axle in the spare-wheel well.

The battery assembly consists of the following components:

- High-voltage battery (in protective housing)
- E-box with service disconnector (allows disconnection of other hybrid components from the power)
- Battery manager (on side of E-box)
- Ventilation system (battery cooling)
- Connections for high-voltage cable
- Sensors in the high-voltage battery (temperature, module voltages)



1 High-voltage battery
2 Supply air ducts (from the cabin)
3 Service disconnector (on the E-box)
4 High-voltage connections
4 Low-voltage connections
- Electric fan
- For control/CAN bus
5 Housing for two electric fans
6 Frame protection box

For reasons of safety, the battery is divided into two units that each contain 140 cells. 10 cells incorporated into each module generate 2 x 144 volts, which are connected in series via the service disconnector to produce a total of 288 volts.

Refer to the following table for more key data relating to the high-voltage battery.

Feature	Value/Description	Feature	Value/Description
Battery type	Nickel-metal hydride	Weight	Approx. 176 lbs (80 kg)
Power	38 kW (electrical)	Operating range At max. power	50 - 100° F. (10 - 38° C.) (for engine start only > - 22° F./30° C.)
Energy content	1.7 kWh	Dimensions	Length 347 mm Width 633 mm Height 291 mm
Voltage	288 V	Efficiency	Approx. 90 %
Number of cells	240 (1.2 volts each)	Cooling	Cooling air from the passenger compartment

The battery has a total energy content of 1.7 kWh. The operating range in which the energy can be used effectively for propulsion is approx. 30 % - 70 %. The effective battery capacity shown in the display on the instrument cluster and the PCM ranges from 0 % - 100 % and is denoted as a relative state of charge. The display actually indicates approx. 40 % (0.68 kWh) of the total energy content of 1.7 kWh is available for driving under electric power only and as a load volume for recovering energy. This operating range takes into consideration the durability requirements of the battery (cyclical strength) and prevents critical battery conditions such as overload or exhaustive discharge.

0.68 kWh
(40 %)

Battery manager (BMS)

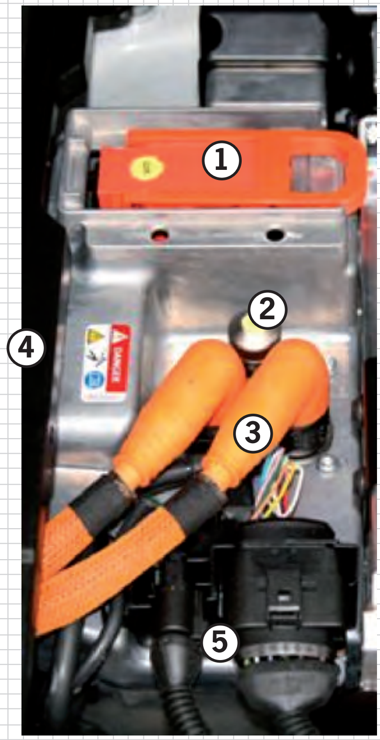
A separate OBD-compatible control unit that monitors all important battery characteristics, processes data and communicates with the hybrid manager is located on the side of the service disconnector and connections. The battery manager (Battery Management System) is connected to the central hybrid manager in the DME control unit via the CAN Hybrid bus and the CAN Drive bus. The input variables include data from the sensors that monitor the module voltage as well as the module and battery temperature, and a current sensor that monitors the SOC (state of charge) and the battery load. The battery manager controls the two fan motors that cool the high-voltage battery. Other important functions of the battery manager include monitoring the electrical isolation of the high-voltage hybrid components from the rest of the vehicle and calculating the battery charge state.

E-box

The connection unit on the high-voltage battery is referred to as the E-box. It is the link between the battery cells and the HV connections for the lines to the power electronics. The E-box receives its commands from the battery manager, a separate control unit in the E-box. The E-box has the following connections:

- 2 DC voltage connections (2 x 144 V plus and minus) at the transition between the high-voltage battery and service disconnector
- 1 DC voltage connection (1 x 288 V plus and minus) for power electronics
- Low voltage for control connection (CAN Hybrid/CAN Drive, fan, etc.)

all of which are described in the following sections.



1 Service disconnector
2 Pilot line connector
3 High-voltage connections
4 Battery manager
5 Low-voltage connections

See chapter "Porsche high-voltage safety concept" !

Contactors

When the service disconnector is plugged in, 2 of the 3 contactors establish the connection between the power electronics and the high-voltage battery. The battery manager activates the 288 volt direct current, which is then supplied to the power electronics. The uninterrupted pilot line that provides the continuous connection between all hybrid components is an essential requirement for activating the current. When the hybrid system starts up, a ballast resistor in the power transmission path is activated to pre-charge the contactors before they switch over and full power is made available.

Service disconnector

A high-voltage fuse connected in series with the battery cells and a contact for the pilot line are located inside the service disconnector. When the service disconnector is pulled out, the high-voltage battery is disconnected from the remaining high-voltage components, which is a fundamental prerequisite for performing work on the high-voltage components.

Thermal management

Cooling the hybrid module

The hybrid module is integrated in the high-temperature circuit of the engine so that heat can be dissipated. When the combustion engine is switched off, an electric auxiliary water pump ensures continued circulation of the coolant.

The hybrid module can be decoupled from the cooling system via a vacuum-controlled rotary disc valve so that the combustion engine heats up more quickly. Sensors measure the temperature in the hybrid module and transmit the value to the control unit in the power electronics.

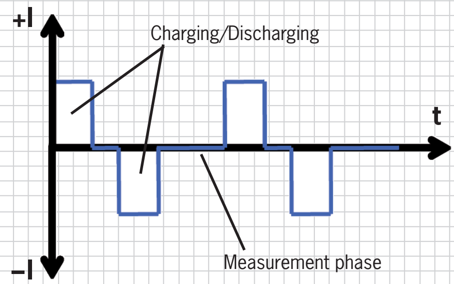
Cooling for power electronics

The power electronics are integrated in the low-temperature circuit on the combustion engine. An electric auxiliary water pump circulates the coolant to make sure the power electronics are always operating at the best temperature. The same cooling circuit is connected to the charge-air cooler integrated in the compressor housing.

Cooling the high-voltage battery

The high-voltage battery reaches maximum power of 38 kW within a temperature range of +50° F. (10° C.) to +99° F. (37° C).

The protected installation position of the battery prevents lower temperatures in practice. If the temperature is still below the minimum threshold, warming pulses are generated through the cyclic application of charge and discharge currents until the temperature reaches the +50° F. (10° C.) threshold. Consequently, Start Stop mode can be activated for the combustion engine after 15 minutes, even if the vehicle is extremely cool throughout.



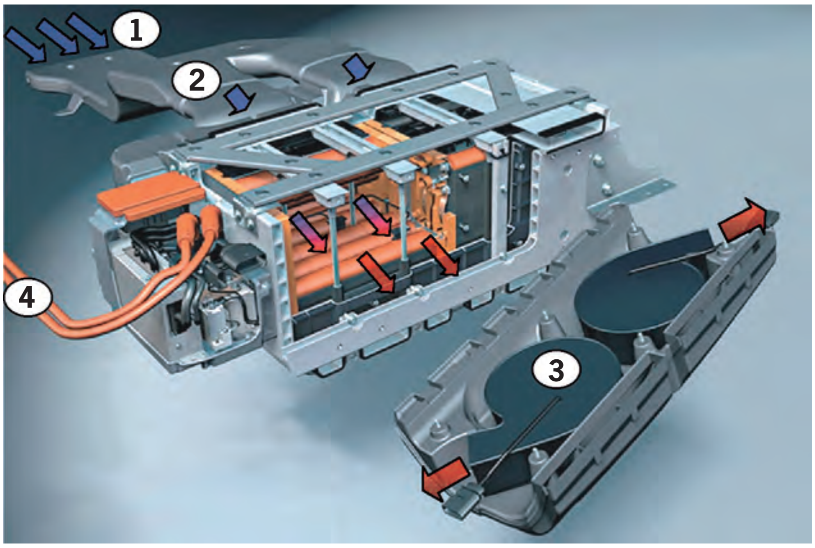
Warming pulses from the high-voltage battery

When the battery is charged and discharged, resistance develops inside the battery and generates heat that must be dissipated in order to prevent the chemicals in the cells from degrading throughout the service life of the vehicle.

Air is drawn from the passenger compartment to cool the battery. The two fans attached to the rear end of the battery housing draw conditioned air directly from the rear passenger compartment and through the battery in order to regulate the battery temperature. The fan control is synchronized in line with the vehicle speed and is hardly audible for the vehicle occupants.

!

The opening in the supply air duct under the rear seats must remain unobstructed so that enough air can be drawn in to cool the battery sufficiently.



1 Opening under rear seats leading to passenger compartment
2 Supply air ducts
3 Electric fans
4 High-voltage lines to power electronics

The aspirated air escapes through openings (forced-air ventilation through plastic slats) in the underbody of the luggage compartment. The battery manager (BMS) monitors regulation of the battery cooling system.

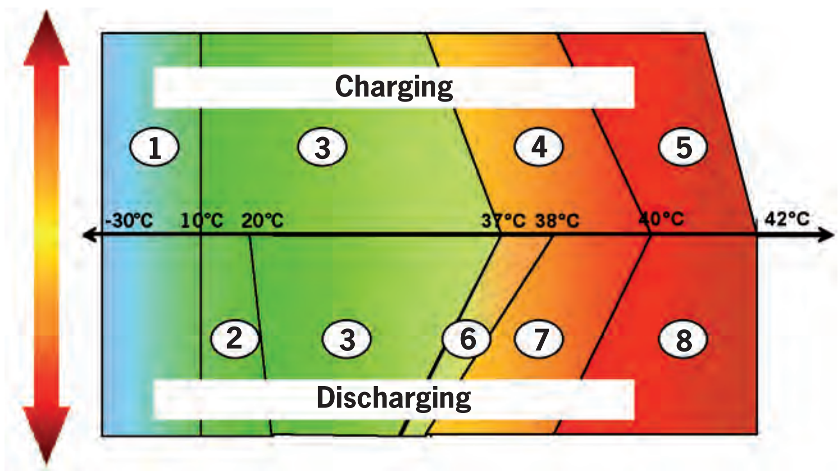
The driver is still responsible for regulating the air conditioning. If the cabin is too warm, the operating strategies are modified in succession to restrict the charging and discharging currents and prevent the temperature from increasing further. As illustrated in the diagram, the charging currents are initially limited to 6 A at 99° F. (37° C.) and recuperation is then reduced if the temperature continues to rise. A reduction in boosting and electric operation also limits discharging accordingly.

Charging

1 Warm-up strategy (warming pulses)
3 No restrictions
4 Charging current limited to 6 A
5 Reduction in recuperation

Discharging

1 Warm-up strategy (warming pulses)
2 Start Stop mode only
3 No restrictions
6 Reduced boosting
7 Reduced driving under electric power
8 Engine restart in Start Stop mode only



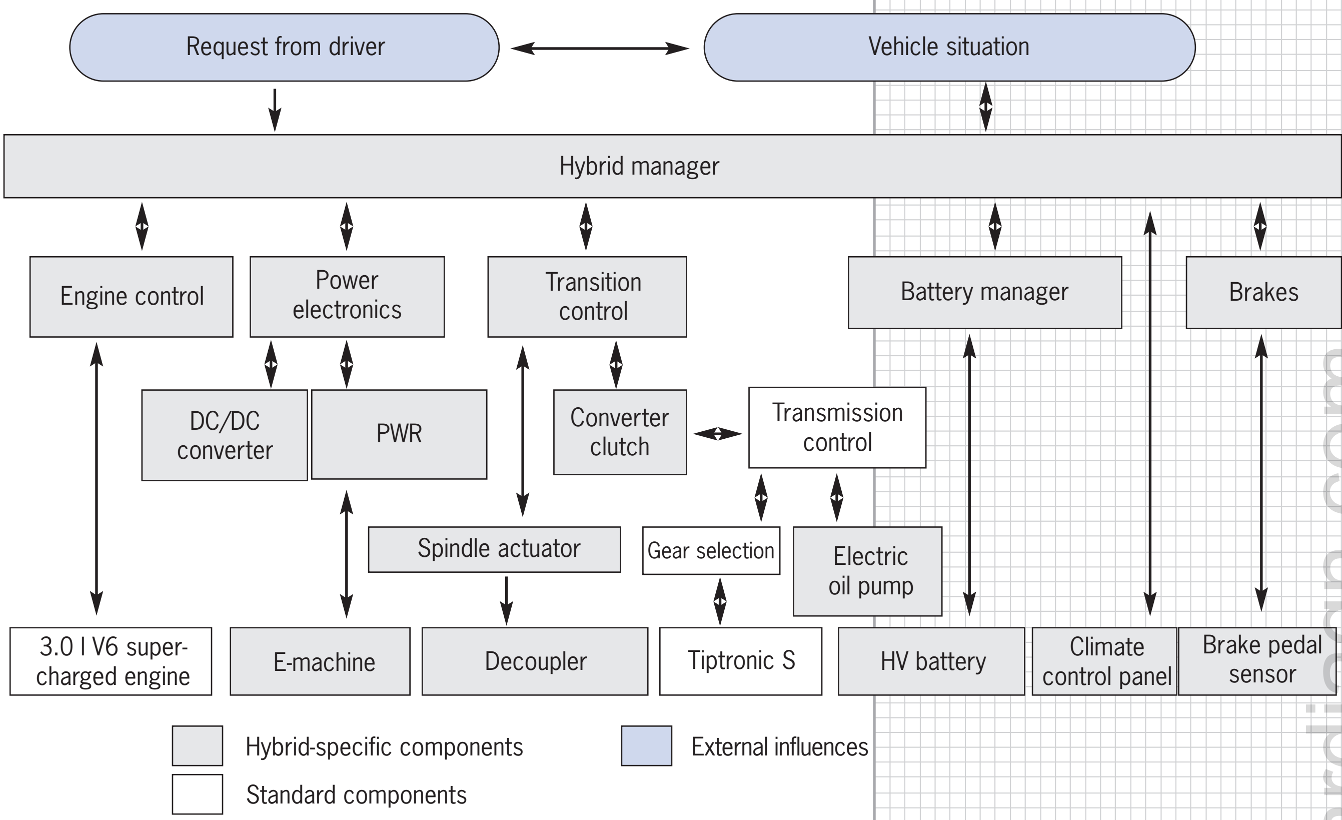
Hybrid manager

The interaction between the combustion engine, hybrid module (electric motor and decoupler), transmission and battery is controlled during the hybrid-specific driving modes via the hybrid manager. The hybrid manager module is located in the DME control unit Bosch MED 17.1.6 together with the control for the combustion engine.

The hybrid manager assists the existing engine control and collects all driving and energy information for the vehicle in order to control the electric motor, combustion engine and all other hybrid components in every driving situation. The hybrid manager uses approx. 20,000 data parameters, whereas around 6,000 are already sufficient for conventional engine control.

DME engine control unit Bosch MED 17.1.6 with hybrid manager

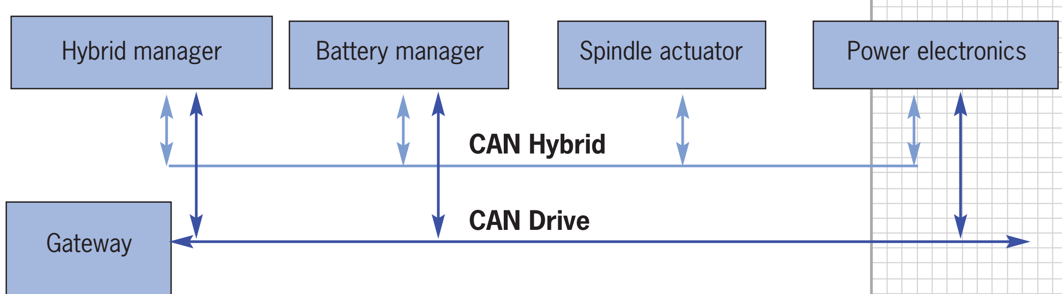
The following overview shows which components are controlled by the hybrid manager.



The hybrid components communicate with one another via the CAN Hybrid bus. The hybrid components link the following assemblies with one another:

- Hybrid manager
- Spindle actuator
- Battery manager (BMS)
- Power electronics

All of these assemblies are also connected to the CAN Drive bus, apart from the spindle actuator.

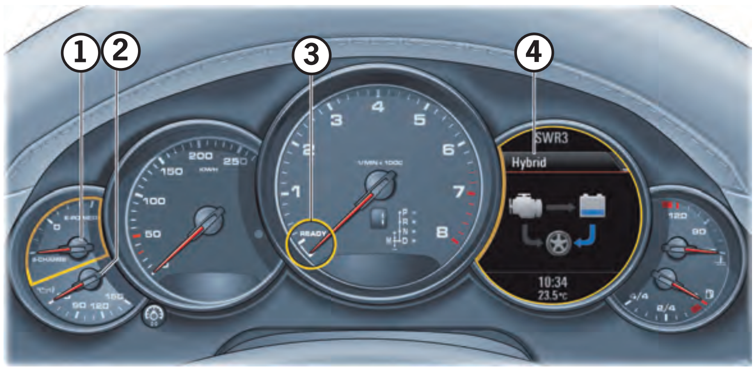


Operation

Like all other Cayenne models, the Cayenne S Hybrid boasts a wide range of comfort and driving functions that have been adapted to the hybrid drive system. Hybrid-specific operating modes such as electric power mode or coasting mode are also available when towing a trailer, driving in reverse gear or driving in manual shift mode.

Displays

There are a number of displays in the instrument cluster and the PCM that indicate the status of the hybrid system and are described here in brief.



1 E-Power meter
2 Oil temperature (unchanged)
3 Ready display in the tachometer
4 Hybrid multi-function display

E-Power meter

The E-Power meter indicates the drive power and energy recuperation rate of the electric motor.

When the needle rests within the E-Power area on the scale, the electric machine acts as a motor and powers the vehicle either alone or in conjunction with the combustion engine. The current consumption is displayed.

When the needle rests within the CHARGE area of the scale (energy recuperation), the E-machine operates as a generator and charges the high voltage battery, e.g. during recuperative braking.

When the needle rests in the 0 position, the electric motor is inactive because the vehicle has stopped and the combustion engine has switched off, for example.

1 Vehicle started and combustion engine off
2 Ignition off

READY display on tachometer

The tachometer has been extended by a "Ready" range, which indicates the starting readiness of both the electric motor and combustion engine when terminal 50 is switched by the ignition key or after an automatic stop.

Multi-function display

The multi-function display in the instrument cluster depicts the flow of energy between the wheel drive, high-voltage battery and combustion engine, and simultaneously indicates the current active hybrid-specific driving mode, i.e. coasting, recuperation, etc.

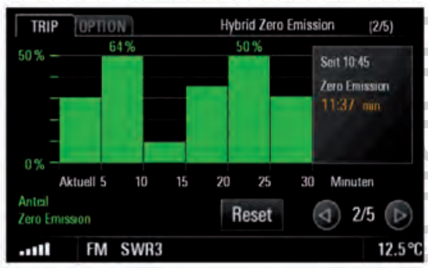
PCM

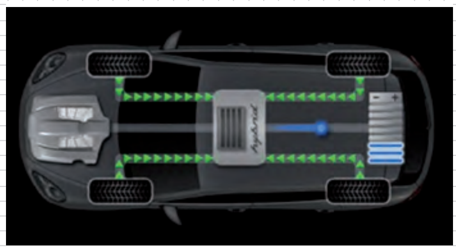
The driver can initiate a statistical evaluation of the driving mode in the PCM system. A bar diagram shows the proportion of driving time without emissions as a percentage value of the total driving time (Hybrid Zero Emission).

The displayed percentage values include all times when the engine is switched off, no fuel is consumed and no emissions are generated.

The consumption-reducing phases are also documented and calculated. These include phases when the electric machine is generating electrical energy in generator mode with the combustion engine switched off (recuperation), when the vehicle is coasting or when the Stop function is active.

The energy flows can also be viewed in the PCM as well as on the multi-function display in the instrument cluster.





Refer to the Hybrid Owner's Manual for more information!

Starting the vehicle

When the ignition is switched on (terminal 15 on), the 12-volt starter battery initially supplies power to the vehicle electrical system and the control units. The contactors in the E-box are only activated when the engine starts (terminal 50). A DC voltage of 288 V is then supplied to the power electronics via the high-voltage cable connections.

The combustion engine only starts when the conditions for electric driving are no longer fulfilled:

• Engine temperature 90° F. (32° C.) or lower
• Charge state of the traction battery is too low to drive solely under electric power

If the charge state of the high-voltage battery is too low to start the combustion engine, Porsche After Sales Service has the option of charging the HV battery using an appropriate charging device.

The high-voltage battery can be charged by the charger only when its charge state is below 30%.

The 12-volt battery can be charged via the 12-volt terminal using a conventional external charging concept.

Stationary vehicle

In parking mode, the battery manager regularly controls the charge state and the voltages in the module. When the vehicle is parked, the entire high-voltage circuit is interrupted by the contactors of the E-box. To prevent the current from draining during phases when the vehicle is stationary and slow down self-discharge of the high-voltage battery.

Hybrid operating modes

The Cayenne S Hybrid can operate in six special driving modes that are only available with a parallel full hybrid and make a decisive contribution to increasing fuel economy.

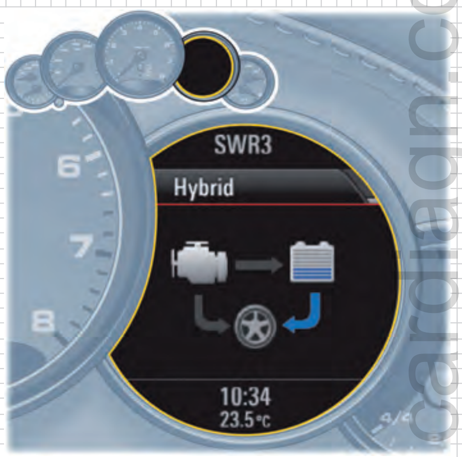
- Driving solely under electric power
- Boosting (addition of combustion engine and E-machine torques)
- Combustion engine powered driving with load point shift
- Coasting (unpowered gliding)
- Regenerative braking (recuperation; i.e. recovery of brake energy)
- Start Stop function

Various conditions that prevent the activation of a hybrid-specific driving mode may exist depending on the system. Limit and threshold values define these criteria. The following overview contains a selection of the most important reasons that prevent the combustion engine from switching off (engine stop vetoes):

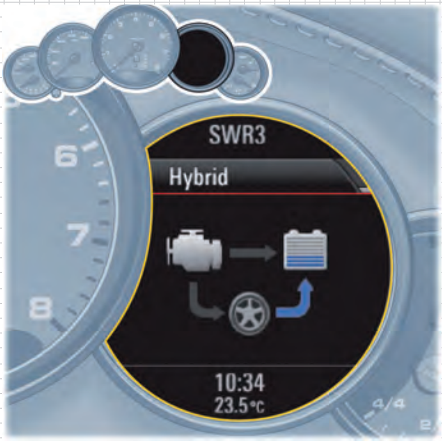
- Driver setpoint torque, vehicle or engine speed too high
- Battery charging state too low or too high
- Engine/Catalytic converter temperature too low
- Battery too warm or too cold
- Gradient too steep
- Hood open (protection for workshop personnel)
- Driver's seat belt not fastened or driver's door open when selector lever in P or N position
- Engine diagnoses active (catalytic converter diagnosis, mixture adaptation)
- Vehicle electrical system power or air-conditioning performance too high

Electric driving

Moving off and driving solely under electric power is possible with a moderate driving style up to a speed of 30 mph (50 km/h). When the E-Power button is pressed (see section "Special functions"), purely electric driving is possible up to approx. 37 mph (60 km/h). The vehicle can drive approx. 1.5 miles (2.5 km) solely under electric power. Current is supplied to the electric motor via the traction battery, which generates 34 kW of power to propel the vehicle. During this time, the combustion engine is switched off and the 12-volt starter battery and the high-voltage battery supply power to the auxiliary units including the vehicle electrical system and consumers (air-conditioning compressor + DC/DC converter).



During operation, the battery manager continually measures the battery charge state and monitors key battery data to prevent critical states such as overheating and exhaustive discharge. Dynamic current limits for charging and discharging are adapted fully automatically. The battery manager then communicates with the hybrid manager and signals whether a load point shift is required to charge the battery or whether discharging is more appropriate to free up capacity for the recovery of brake energy (recuperation).



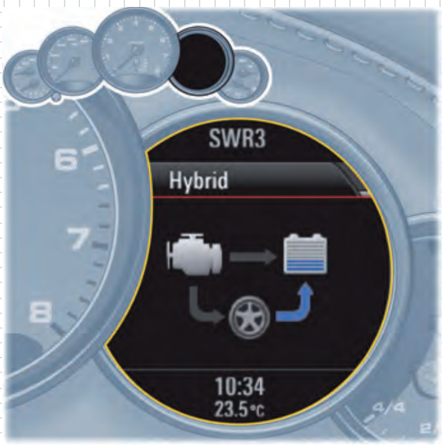
Coasting

Coasting is possible even at low speeds and occurs as soon as the driver releases the accelerator pedal. The decoupler is disengaged and the combustion engine is switched off automatically to prevent the engine drag torque that normally occurs in the overrun phase. There is no drive assistance by the combustion engine or electric motor during coasting. In this case, only air and rolling resistance brake the vehicle. The rotor on the electric motor rotates on the drive shaft during the coasting phase and uses an imperceptible braking torque to generate electrical energy that powers the vehicle electrical system and all connected consumers. The traction battery is deliberately not charged. The alternating current from the electric motor generates 12 V DC or 288 V DC in the power electronics for the air-conditioning compressor. The multi-function display shows the recuperation process.

The maximum coasting speed is limited to 97 mph (156 km/h) or a speed that corresponds to the crankshaft rotation speed of 2,600 rpm. The combustion engine cannot be engaged at a higher speed because otherwise the decoupler would be subject to increased wear.

Coasting strategy

At speeds below 30 mph (50 km/h), a low electrical overrun torque is generated deliberately because a "coasting" driving style is difficult to achieve in an urban environment. The recuperative energy generated is also used to charge the high-voltage battery.



Recuperation

In engineering, this term usually refers to a technique for recuperating energy.
In recuperation driving mode, the electric motor operates as a generator. The generated electrical energy is used to charge the high-voltage battery and supply power to all electric consumers simultaneously.
The hybrid management system recuperates energy in the following situations:

- The vehicle coasts (when the Sport button is pressed or travels at speeds < 30 mph (50 km/h) –> see chapter "Coasting"
- The vehicle moves off/coasts downhill (gradients > 4 %)
- During braking

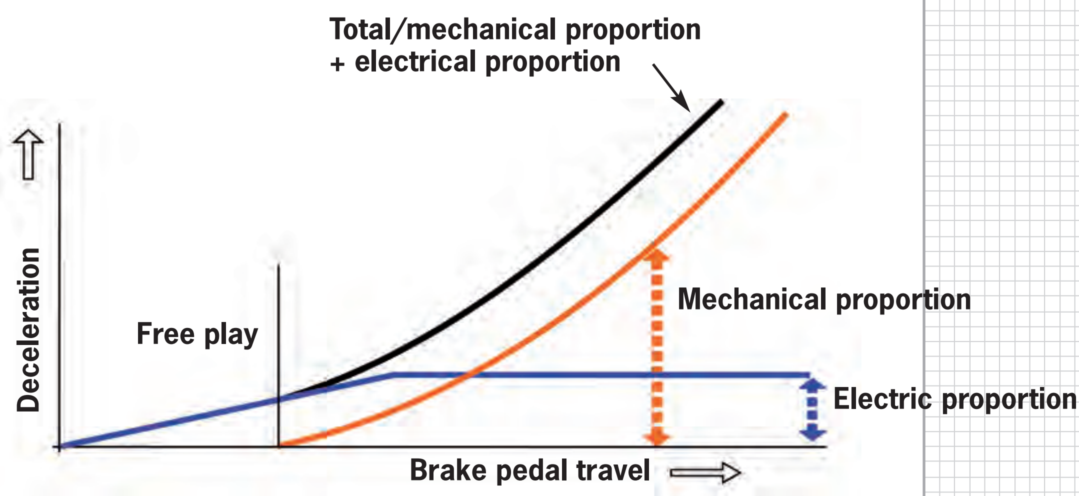
Driving downhill

The hybrid management system switches from coasting mode to recuperation mode when the gradient exceeds 4 % and produces an increasing braking torque so that the vehicle does not accelerate too sharply.

Braking

The E-machine produces a braking torque in the free travel range of the braking pedal before hydraulic brake pressure is actually generated. The free play of the pedal was increased by 4 mm for more precise control. The hybrid manager regulates the braking force share from the electric motor in line with the pedal travel and vehicle speed.

Refer to the chapter "Chassis" for more information.

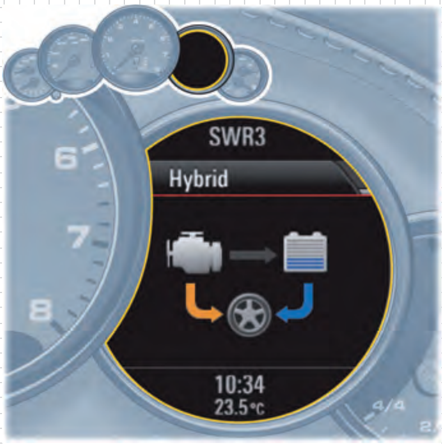


The E-Power meter in the instrument cluster provides the driver with information on the function of the electric motor during the recuperation of energy (charging) in generator mode.

If the charge state of the battery does not allow further recuperation, the combustion engine starts in order to generate braking torque.

While the braking torque of the electric motor is systematically reduced during coasting, the hybrid manager systematically increases the generator power during recuperation by raising the voltage level in the stator coil on the E-machine to increase the current flow when the rotor rotates. The higher generator power acts as an increasing braking torque on the drive shaft and decelerates the vehicle.

The effect of the mechanical brake system and the generator power of the electric motor combine to produce the total braking power, whereby the braking power of the electric motor reaches a maximum limit in the lower speed range in a similar way to the drive power and the mechanical component is dominant at higher speeds.

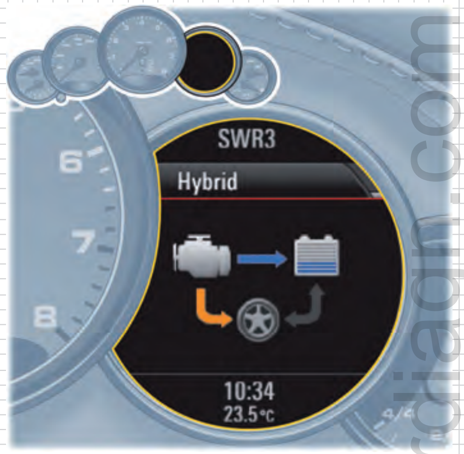


E-boost

The hybrid drive incorporates an E-boost function, which is similar to the kickdown function in combustion engines that provides maximum engine power. When this function is activated, the E-machine and combustion engine deliver their maximum power, which adds up to a higher overall value. The sum of the individual power outputs from the two drive types equals the total power of the drive train. A total torque of 580 Nm and total power of 279 kW are generated in E-boost mode. The operating time of this function is limited to a maximum of 10 s.

Load point shift

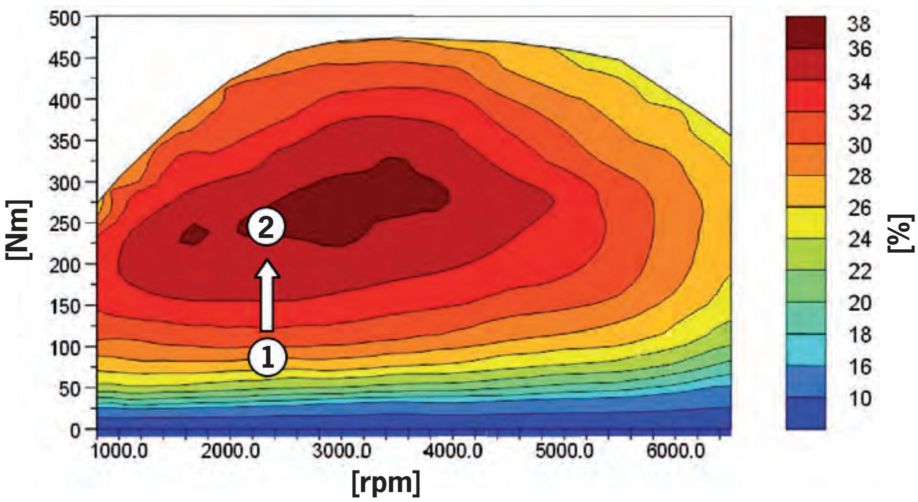
Each power unit operates most economically within a specific load range. If the combustion engine operates at partial load below this range or at full load above this range, the energy produced from the fuel is not utilized economically. The hybrid management system always attempts to operate the combustion engine within the most efficient range. At the same time, Porsche synchronises the operating points of the remaining assemblies, E-machine and high-voltage battery with the combustion engine so that the overall system operates with maximum efficiency. The aim of synchronization is not to drive as far as possible solely under electric power, but to ensure that the smallest amount of energy is consumed when the battery is charged.



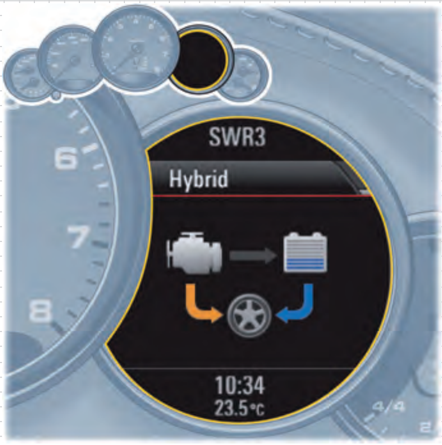
Load point shift

If the current load point is below the optimum range, the hybrid management system switches the E-machine to generator mode while simultaneously opening the throttle. The "excess" mechanical energy is used to charge the traction battery. Absolute vehicle consumption increases when the load point is shifted upwards but from a relative perspective, the fuel is used more efficiently and the vehicle range under electric power without emissions is extended. The driver will not notice the shift in the load point because neither the engine nor the vehicle speed changes. The vehicle behaves as if it were driving at a constant speed along level terrain that merges into a gradient.

A diagram depicting the energy flows after the load increase appears on the multi-function display. The graph below illustrates a load point increase at approx. 2,400 rpm. The efficiency of the combustion engine can be increased by about 10 % (range 1 28 % –> range 2 38 %).



1 Inefficient load point
2 Load point within optimum range
[Nm] Torque
[rpm] Engine speed
[%] Efficiency



Load point reduction

If the load point exceeds the most economical range because of the driver setpoint torque and the charge state of the battery allows this, the E-machine assists the combustion engine (see Boosting) until the charge state (SOC) falls below the minimum level for this operating mode. As a result, fuel consumption and exhaust emissions are reduced considerably and a sporty driving style is possible.

The load decrease also appears on the multi-function display.

Auto Start Stop function

In a conventional vehicle with Start Stop system (see micro hybrid), the vehicle must stop in order to deactivate the combustion engine. The Porsche Cayenne Hybrid is a full hybrid vehicle that can be driven solely under electric power. This characteristic enables the Auto Start Stop function to deactivate the combustion engine even when the vehicle is driving or rolling. The hybrid manager makes the decision here.

Engine start

The combustion engine is started automatically in the following cases:

- vehicle started using the key and battery temperatures lower than 50° F. (10° C.)
- cabin air conditioning system issues a heating request
- if the driver setpoint torque is high (accelerator pedal) or the load is increasing (e.g. on inclines) and the E-machine alone cannot provide sufficient power
- if the charge state of the high-voltage battery is low
- if the vehicle speed increases
- - > 30 mph (50 km/h)
- - > 45 mph (60 km/h) if the E-Power button is active
- when the driver's seat belt is released
- when the driver’s door is opened
- when the hood is opened
- when driving over steep terrain and if the Tiptronic S is about to perform a downshift that causes the engine speed to exceed the limit of 2,600 rpm
- when switching back to a load phase from coasting mode or if recuperation is initiated and fulfils the above conditions

Engine stop

An automatic engine stop is always performed when the power train or discharged battery require power. The rev counter then moves to the Ready position. The hybrid management system prevents the engine from stopping:

- if the engine or vehicle speed is too high (>97 mph (156 km/h) or >2,600 rpm)
- if the battery charge state (SOC) is too low
- if the battery charge state is too high and engine braking torque is required
- if the hood is open
- if the driver's seat belt is not fastened in P or N
- if the driver's door is open in P or N
- if faults have been detected/clutch is in emergency mode
- if engine diagnoses are running (catalytic converter, mixture adaptation, etc.)
- during the minimum operating time after initial start
- if the gradient is steeper than 7 %
- if cabin heating is required
- if the vehicle electrical system power or air-conditioning performance is too high
- if the engine/catalytic converter temperature is too low
- if the high-voltage battery is too warm or too cold < 50° F. (10° C.) or > 108° F. 42° C.)

Special functions

Sport button

The Sport function is activated by pressing the Sport button in the center console.

Effects:

- Pressing the Sport button or performing a kickdown initiates an immediate downshift, depending on the engine speed. The shift points of the Tiptronic S are changed towards a higher rpm range.
- Coasting mode is limited to approx. 45 mph/70 km/h (otherwise 97 mph/156 km/h).
- The recuperation torque of the E-machine is increased during coasting mode. The vehicle handling is similar to the handling in combustion engine mode.
- The combustion engine operates with an unlimited full-throttle characteristic (full throttle is usually limited).
- A steeper pedal map is used.
- The E-boost is activated from an accelerator pedal position of 80% (max. 10 s).
- The "Sport" display lights up in the instrument cluster.

E-Power button

Pressing the E-Power button in the centre console increases the availability of electric driving mode. This mode was designed primarily for emission-free operation in residential areas and covered car parks. A flatter characteristic line is used for the accelerator pedal to allow better vehicle control. The combustion engine starts later and more power is recuperated when the engine is operating.

The combustion motor is no longer operated in the best operating range due to the change in operating behaviour. Consequently, fuel consumption increases if E-Power mode is used frequently.

When the button is activated, a light-emitting diode in the button lights up and "E Power" appears in blue in the instrument cluster.

Conditions for activating E-Power mode include:

- sufficiently high battery charge state
- vehicle speed < 34 mph (55 km/h)
- battery temperature between 59° F. (15° C.) and 104° F. (40° C.)
- no heating request from the air-conditioning

E-Power mode is interrupted and then reactivated if:

- the charge state falls below the minimum level
- power requirements are too high

E-Power mode is deactivated:

- when the maximum driving speed is exceeded (purely electric driving)
- when Sport mode is activated or
- if the E-Power button is pressed again

Fuel consumption

The Porsche Cayenne S Hybrid achieves a much lower nominal fuel consumption rate than the conventional Cayenne S with an equivalent output as well as an extremely sporty performance. The individual driving style has a greater effect on hybrid vehicles than vehicles with a conventional drive.

“Hybrid-adapted“ driving means:

- driving with foresight, releasing accelerator pedal early
- inducing long coasting phases by deliberately lifting your foot completely off the accelerator
- from an energy perspective, coasting is much more effective than recuperation!
- performing long even braking actions with minimal brake pedal travel is the best way to achieve a high proportion of recuperative power
- avoid operating at full throttle
- if the charge state is high, drive under electric power deliberately until the charge state moves back to the central area
- continuous use of the E-power button or Sport mode increases fuel consumption
- economical use of auxiliary consumers such as seat heating, heated rear window, etc.

The reduction in fuel consumption becomes particularly noticeable if an appropriate driving style is adopted in urban environments.


S VM 9200

2 DME engine electronics

General

A supercharged 3.0 l V6 engine with direct fuel injection (DFI) is used for the first time in the new Cayenne S Hybrid. This highly efficient vehicle features a full parallel hybrid drive (3.0 l V6 DFI 245 kW supercharged engine and powerful 34 kW electric machine).

In addition to ensuring typical Porsche driving characteristics with V8 performance, the development goal was to achieve low fuel consumption, reduced CO_2 emissions and compliance with all worldwide emission standards. The Cayenne S Hybrid delivers the efficient performance expected of a Porsche in a completely new way.

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Safety instructions 108
Engine specifications Cayenne S Hybrid (3.0 l V6 DFI supercharged engine) 108
DME control unit Bosch MED 17.1.6 (hybrid manager) 109
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Fuel supply, high-pressure side DFI 121
Injection strategies 123
Ignition system 123
Intake system/Turbocharging 124
Exhaust system 129
Secondary air injection 130

Safety instructions

The safety instructions must be observed during work on the Cayenne S Hybrid.

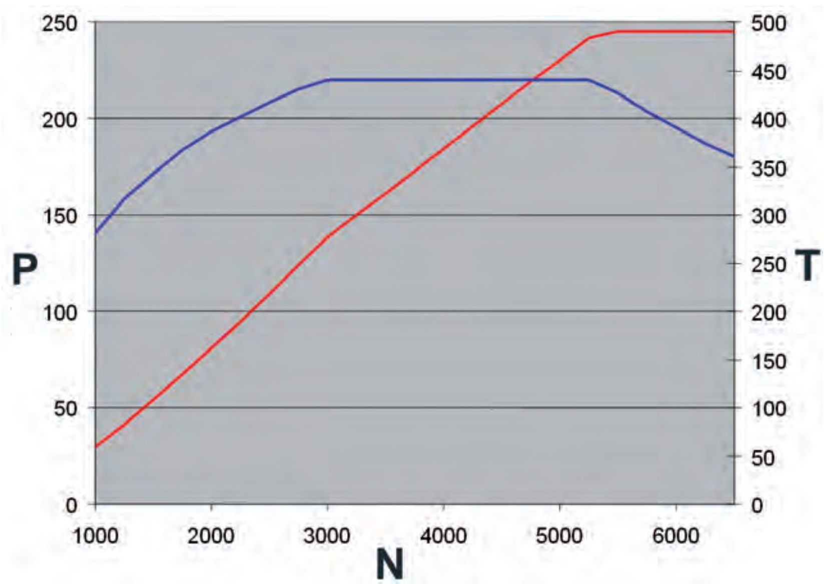
All work on hybrid vehicles may only be performed by qualified staff.

For further information, see the

- "Cayenne S Hybrid Training Information" and the
- "PIWIS Information System".

Engine specifications Cayenne S Hybrid (3.0 l V6 DFI supercharged engine)

The combustion engine produces **333 hp (245 kW)** at 5,500 rpm to 6,500 rpm and delivers a maximum torque of **440 Nm** in the range between 3,000 rpm and 5,250 rpm.



P Power output in kW

N Engine speed in rpm

T Torque in Nm

Power curve (red line)

Torque curve (blue line)

DME control unit	Bosch MED 17.1.6
Displacement	3.0 liters
Power	333 hp (245 kW) 5,500 - 6,500 rpm
Torque	440 Nm 3,000 - 5,250 rpm
Compression ratio	10.5
Idle speed	800 rpm
Max. engine speed	6,500 rpm
VarioCam (intake)	42° NW
Fuel consumption AT (NEDC)	8.2 l/100 km
CO_2 emissions	193 g/km

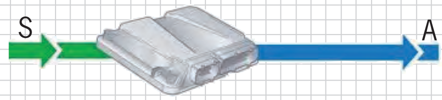
DME control unit Bosch MED 17.1.6 (hybrid manager)

On the following pages the incoming sensors and the controlled actuators of the DME control unit are described.

S Sensors

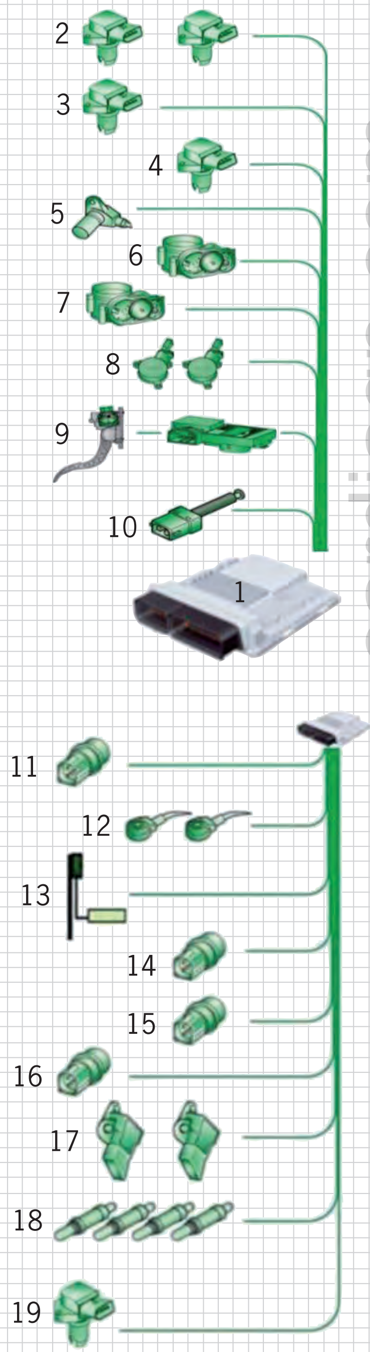
A Actuators

DME DME control unit Bosch MED 17.1.6



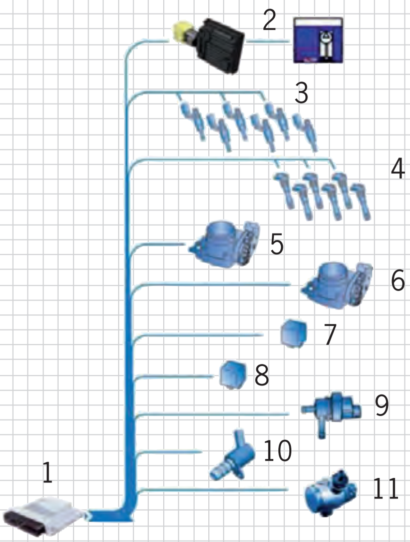
DME sensors

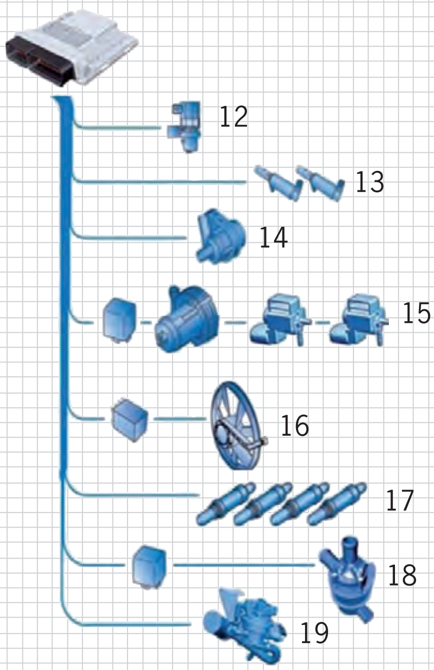
1 DME control unit Bosch MED 17.1.6
2 Boost pressure and temperature sensor (bank 1 + 2)
3 Intake manifold pressure and intake air temperature sensor (downstream of electronic throttle)
4 Sensor for secondary air pressure (USA vehicles only)
5 Engine speed sensor
6 Potentiometer for throttle valve position (electronic throttle)
7 Potentiometer for bypass valve position (for boost pressure control)
8 Hall sender for intake camshafts (bank 1 + 2)
9 Accelerator pedal sensor 1 + 2
10 Hall sensor for brake light switch on brake master cylinder
11 Fuel pressure sensor for low pressure (in the low-pressure line upstream of the high-pressure pump)
12 Knock sensors (bank 1 + 2)
13 Sensor for fuel level (CAN)
14 Oil pressure switch
15 Oil pressure switch for reduced oil pressure
16 2 coolant temperature sensors (for measuring the inlet and outlet temperature at the cylinder head)
17 Potentiometer for intake manifold flap (bank 1 + 2)
18 Oxygen sensor (LSU 4.9) upstream of catalytic converter bank 1 + 2
Oxygen sensor (LSF 4.2) downstream of catalytic converter bank 1 + 2
19 Fuel pressure sensor for high pressure



Other sensors

- A pressure sensor for the vacuum system
- A brake pedal sensor
- A sensor for oil level and oil temperature
- CAN - input signals





DME actuators

1 DME control unit Bosch MED 17.1.6
2 Control unit for low-pressure fuel pump and low-pressure fuel pump
3 Fuel injectors, cylinders 1 - 6
4 Individual ignition coils for cylinders 1 - 6
5 Throttle valve control unit (electronic throttle)
6 Bypass valve control unit (for boost pressure control)
7 Power supply relay (for engine components)
8 Power supply relay (for DME control unit)
9 Tank vent valve
10 Valve for oil pressure control
11 Quantity control valve for high-pressure control
12 Valves for intake manifold flaps (bank 1 + 2)
13 Valves for intake camshaft control (bank 1 + 2)
14 Water pump for charge-air cooling
15 Relay, secondary air pump, secondary air injection valve (bank 1 + 2)
16 Control unit for radiator fan, radiator fan
17 Oxygen sensor heater, upstream and downstream catalytic converter
18 Relay for auxiliary water pump, auxiliary water pump
19 Diagnosis module for tank leaks (for USA vehicles only)

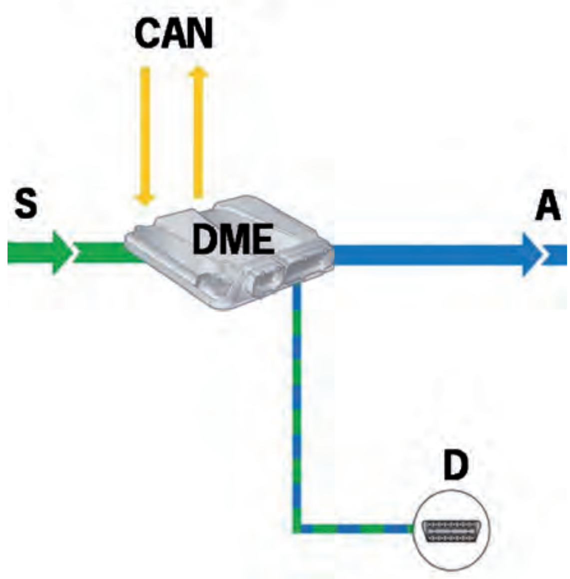
Other actuators

- Switching valves for thermal management
- An electric water pump for the high-temperature circuit
- An electric water pump for the low-temperature circuit
- An encased main water pump
- An electric vacuum pump

DME control unit Bosch MED 17.1.6 (hybrid manager)

The DME control unit Bosch MED 17.1.6 also contains the hybrid manager, which is responsible for controlling the hybrid components and electric auxiliary units of the engine. Communication between the DME and hybrid manager takes place internally in the common control unit.

External communication with other control units takes place via the 500 kbd CAN-BUS or the diagnostic connection of the vehicle.

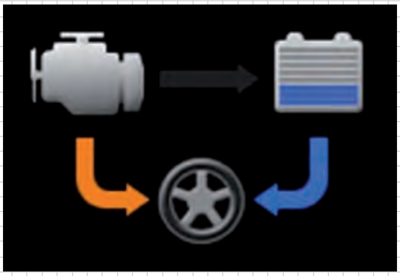


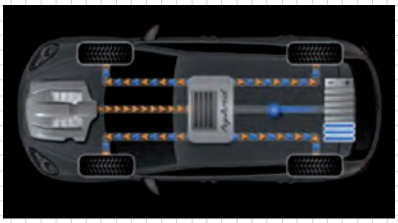
S Sensors
A Actuators
D Diagnostic connection
CAN CAN bus connection
DME DME control unit Bosch MED 17.1.6

Electric auxiliary units

Since the combustion engine does not run continuously, individual auxiliary units are powered electrically in order to guarantee continuous operation:

- Electric high-voltage air-conditioning compressor for cabin air conditioning
- Electric auxiliary vacuum pump for brake power boost
- Electric servo pump for power steering
- Electric auxiliary oil pressure pump for transmission oil supply
- Two electric auxiliary water pumps (one for the high-temperature circuit and one for the low-temperature circuit)
- Electro-hydraulically operated spindle actuator for actuating the decoupler in the drive train



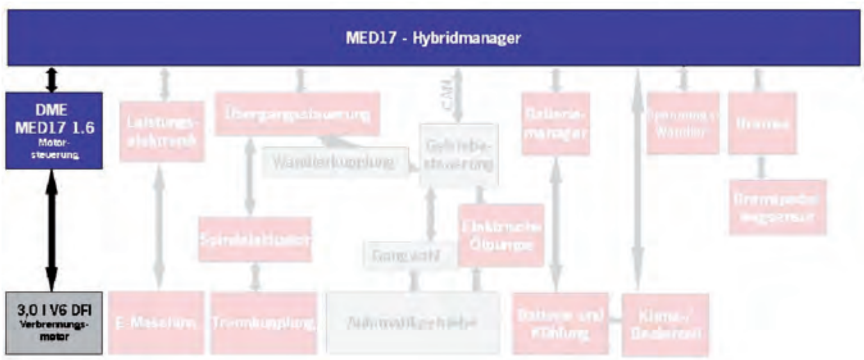


Cayenne S Hybrid-specific driving modes

Six special driving modes

- Driving under exclusively electric power
- Gliding without drive power ("coasting")
- Recovery of brake energy (recuperation)
- Combustion engine-powered driving with load point shift for charging the traction battery
- Boosting (addition of combustion engine and electric machine torques)
- Automatic stopping and restarting of engine when the vehicle is stationary (Auto Start Stop function)

The interaction between the main components of combustion engine, hybrid module (electric machine and decoupler), transmission and battery is controlled during the hybrid-specific driving modes via the hybrid manager. The hybrid manager expands the existing engine control and collects all driving and energy information for the vehicle in order to be able to control the electric machine and the combustion engine for optimum fuel consumption in every driving situation. As the supplier of energy, the battery is neither discharged too exhaustively nor, with respect to the number of cycles, loaded and unloaded too frequently. For this calculation, approx. 26,000 data parameters in total must be defined in the control unit, while around 10,000 are sufficient for conventional engine control.



The DME functions are controlled by the hybrid manager.

- Actuation of the hybrid clutch and the DME activates the Auto Start Stop function for the combustion engine depending on the driver requirements and the vehicle situation
- Definition of functions e.g.:
  - Coasting
  - Recuperation
  - Load point shift
  - Boosting

Auto Start Stop function

Thanks to the hybrid technology, a Start Stop function can be integrated into this vehicle concept. In a conventional vehicle with Start Stop system, the vehicle must stop in order to deactivate the combustion engine. With a full hybrid vehicle, the vehicle can be driven electrically. This characteristic enables the Auto Start Stop function to deactivate the combustion engine even when the vehicle is driving or rolling. The combustion engine is activated as required. This may be the case during high acceleration, high speed, high load or low charge state of the high-voltage battery. When the high-voltage battery is in a low charge state, the hybrid system can use the combustion engine with the E-machine as a generator to charge the high-voltage battery. In other cases the full hybrid vehicle can be driven electrically. The combustion engine is then in a Stop phase. This also applies to slow-moving traffic, stopping at a red light, deceleration when driving downhill or coasting of the vehicle. When the combustion engine is not running, it does not consume any fuel and thus cannot produce any emissions. The Start Stop function integrated in the hybrid system increases the efficiency and thus the eco-friendliness of the vehicle. During the Stop phase of the combustion engine, the air conditioning can still be operated. The air-conditioning compressor is part of the high-voltage system.

Coasting

Coasting is possible even at low speeds and occurs as soon as the driver releases the accelerator pedal. The decoupler is disengaged and the combustion engine is switched off automatically in order to prevent the engine drag torque that normally occurs in the deceleration phase. Coasting is thus equated with gliding or rolling without any combustion engine powered or electric drive support.

Recuperation

As soon as the driver actively reduces the vehicle speed, rolls or drives downhill, the hybrid manager separates the combustion engine from the rest of the drive train and switches it off. The E-machine then functions as a generator and first and foremost charges the high-voltage battery. The hydraulic brake system is activated from a defined pedal travel.

Load point shift

A load point shift can be carried out by the hybrid manager as a load point increase or reduction.

For a load point increase, the combustion engine provides more torque than the driver setpoint torque, whereby the electric machine of the vehicle compensates for the difference through charging of the high-voltage battery by the combustion engine.

For a load point reduction, the combustion engine provides less torque than the driver setpoint torque and the electric machine of the vehicle compensates for the difference by way of the engine, which results in discharging of the high-voltage battery.

Boosting

Similar to the kickdown function in combustion engines, which makes the maximum engine power available, E-machines and combustion engines deliver their maximum power, which adds up to produce a higher overall value.

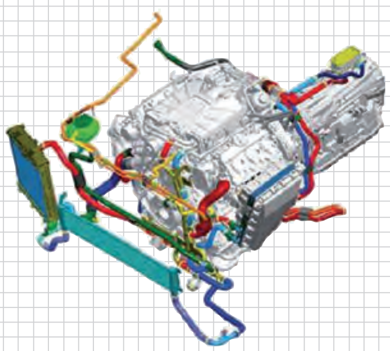
For further information, see the brochure "Cayenne S Hybrid Training Information", section "DME Hybrid technology".

Thermal management

The DME control unit also controls thermal management.

Tasks of the cooling system with thermal management

- Bringing the engine to the optimum operating temperature and controlling this temperature.
- Controlling the cooling and heat distribution between:
  - Combustion engine with high-temperature circuit and low-temperature circuit
  - Transmission
  - Passenger compartment
  - Charge-air cooler, bank 1 and 2
  - E-machine
  - Power electronics

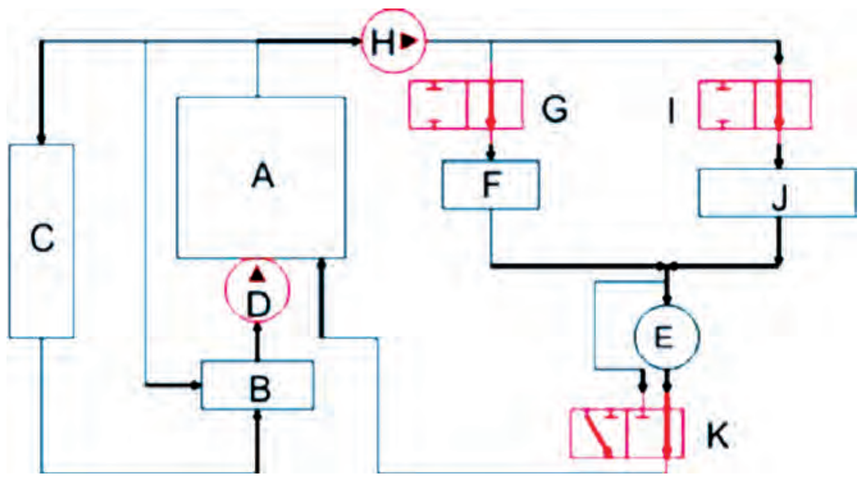


The illustration shows the high-temperature circuit and low-temperature circuit of the engine.

All Cayenne engines meet the high demands placed on a Porsche engine under all operating conditions and therefore also meet the special requirements that apply to hot countries. The Cayenne S Hybrid is designed to meet all performance requirements whether on-road, off-road or in traction mode. The main areas of the thermal management system in the Cayenne S Hybrid are heat distribution between the combustion engine, transmission and passenger compartment.

The basic goal is to ensure that all components reach their optimum operating temperature as quickly as possible and to also meet the comfort demands of passengers by heating up the cabin quickly. At low temperatures and for cold engine starts in particular, it is important to manage the low amount of available heat in the best possible way. Efficient use of the available heat helps to save fuel, reduced CO_2 emissions and comply with strict emission regulations.

High-temperature circuit (for engine cooling)



A Engine
B Thermostat
C High-temperature cooler
D Main water pump (switchable/encased)
E E-machine
F Transmission oil cooler
G Transmission shut-off valve
H Auxiliary water pump
I Heating shut-off valve
J Heat exchanger
K Electric motor bypass valve

Effect of thermal management

- Reduced cooling performance during the engine operation phase
- This results in faster heating of the transmission and engine oil
- Less internal friction in the engine and transmission components

Result

- Reduced fuel consumption
- Faster heating of the passenger compartment (with priority over engine oil heating)
- Increase in fuel economy of up to 1.5% approx.

The cooling system is part of the thermal management system and has two circuits which can be regulated depending on the coolant temperature. In the Cayenne S Hybrid, this is done by an electrically operated, map-controlled and deactivatable thermostat.

A Power electronics
B Charge-air cooler
C Low-temperature cooler (max. 140° F. (60° C.)
D Auxiliary water pump
E Hose thermostat

!

Further information on thermal management with high-temperature circuit and low-temperature circuit is provided in the brochure "Cayenne S Hybrid Training Information", section 1 "Combustion engine".

Cold engine

When the bowl on the main water pump is closed in a cold engine, the water remains in the cylinder head and crankcase to heat the engine more quickly (stationary water).

Warm-up

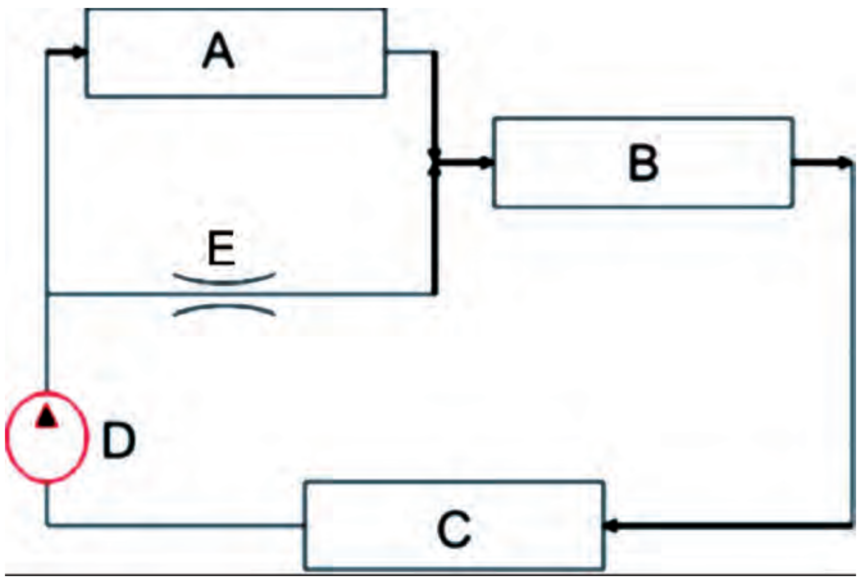
Depending on the increase in engine temperature, the coolant flow through the engine (small circuit) is activated during warming up.

Engine at operating temperature

After this, the coolant radiator is activated (large circuit) depending on the engine operating point and based on a map stored in the engine control. The map control of the thermostat then regulates the coolant temperature between 201° F. (94° C.) and 221° F. (105° C.) depending on load and thus ensures optimum friction conditions in the engine that are adapted to the load point.

When the heating shut-off valve is opened and the auxiliary water pump is connected automatically, warm water is supplied to the heating system.

Low-temperature circuit (for power electronics and charge-air cooling)



The low-temperature circuit is responsible for temperature control of the charge-air coolers and power electronics.

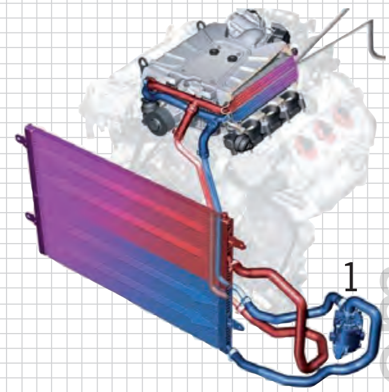
Charge-air cooling, low-temperature circuit

Electric water pump for charge-air cooling

A PWM signal from the DME control unit controls the pump based on a program map.

In the event of an interruption in the signal, the DME control unit switches to 100% pump capacity.

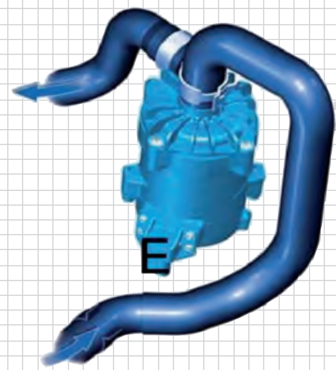
The pump is activated according to the temperature taken from a map in the engine control unit downstream of the charge-air coolers and the pressure downstream of the charge-air coolers. It always runs from 1,300 mbar or from a coolant temperature of 122° F. (50° C.). The pump is controlled by the engine control unit via a PWM signal. The pump electronics use this signal to calculate the required pump speed and control the electric motor. If the pump is working correctly, the pump electronics send the current pump speed back to the DME control unit via the bidirectional signal line. This process runs cyclically throughout pump operation.



1 Electric water pump

Effects in the event of faults

If the pump electronics detect an error, the PWM signal changes, i.e. either the pump speed is reduced or the pump is switched off. The changed signal is evaluated by the engine control unit. As the reduced power is only noticeable at full throttle and exhaust gas is not affected in the event of failure, the Check Engine light (MIL) is not activated. No direct reaction is triggered in the engine control unit in the event of pump failure. However, the charge air temperature is monitored. If this is found to be too high, the engine power is reduced.



E Electrical connection

If the signal line to the pump is interrupted or there is a short circuit to B+ on the signal line, the pump switches to emergency mode, in which it delivers 100% output. The pump stops in the event of a short circuit to ground on the signal line.

Other DME functions

1 **Vehicle electrical system recuperation** in communication with the gateway control unit

This control operation includes the DME control unit, the gateway control unit, the brake pedal sensor, starter battery with battery sensor, the generator and the vehicle electrical system.

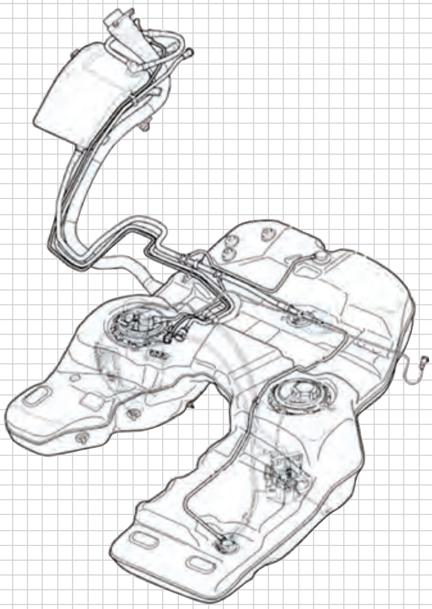
2 **Differential Hall sensor** for detection of the engine speed, reference mark and engine direction of rotation

3 **Sport button** as standard

4 **Activation of VarioCam** on intake camshafts

5 1 steplessly **controlled radiator fan** 0 to 600 W

6 Communication with the control unit of the **adaptive cruise control** (ACC)



Fuel supply, low-pressure side

Fuel quality

The engines are designed for unleaded premium fuel 93 octane ($\frac{R+M}{2}$). If fuel with a lower number is used, corresponding adaptation is performed by the knock control.

Fuel tank

The fuel tank has a filling capacity of 22.4 gal. (85 l),reserve 3.4 gal. (13 l) or optional 26.4 gal. (100 l).

ReturnLess Fuel System - RLFS

Consisting of:

- 1 demand-controlled electric fuel pump
- Fuel filter (lifetime filter in the tank)
- Fuel-pressure regulator (fuel pressure approx. 83 psi/5.7 bar max.)

The low-pressure side of the fuel supply system consists of a returnless fuel system (RLFS - ReturnLess Fuel System). The variable-speed electric fuel pump delivers the fuel via the fuel filter and fuel-pressure regulator (in the fuel tank) to the quantity control valve on the high-pressure pump with a max. pressure of approx. 83 psi (5.7 bar). The sucking jet pumps in the fuel tank are also operated with the low-pressure side.

The two fuel-level sensors are installed in the fuel tank for measurement of the fuel level.

Control unit for electric fuel pump

Operating principle

The control unit of the electric fuel pump is installed at the rear above the right side of the fuel tank (access via the wheel housing liner at the rear right). It is used for stepless control of the electric fuel pump. This control unit receives the setpoint speed for the fuel pump from the DME control unit via a bidirectional PWM interface and feeds back diagnosis information.

Power supply

The control unit has a power supply with +.
Terminal 31 represents the connection to vehicle ground.

Control input

The output of the fuel pump is controlled by the DME control unit by a PWM control signal. This bi-directional PWM interface is also used for diagnosis of the control unit for the electric fuel pump.

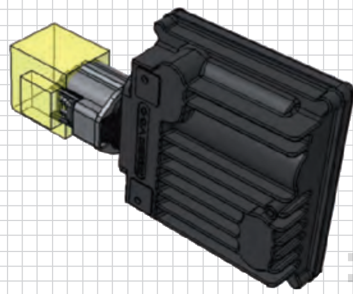
Electric fuel pump

The speed of the electric fuel pump is regulated by way of the specified frequency within the power limits of the fuel pump (with limitation of the phase current) and independently of the vehicle electrical system voltage (voltage compensation). The pump motor is a 3-phase synchronous motor without position feedback and without sensor.

Note on the control unit for electrical fuel pump on the Cayenne

On the Cayenne S Hybrid, the fuel pump delivery rate can be reduced to such an extent that the fuel pressure falls from approx. 83 psi (5.7 bar) to below 58 psi (4 bar), depending on the fuel requirement. The low pressure is detected by a pressure sensor for this. The fuel pressure sensor for detecting the low pressure is installed in the high-pressure pump supply line.

This control function differs from the V8 engines, which have a constant fuel low pressure of approx. 83 psi (5.7 bar).



Diagnostic information on the PWM signal and diagnosis is described in Guided Fault Finding.

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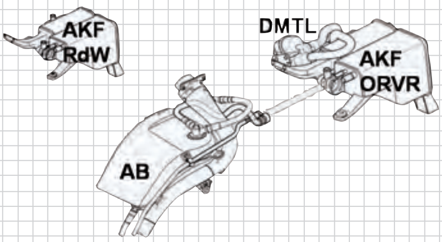
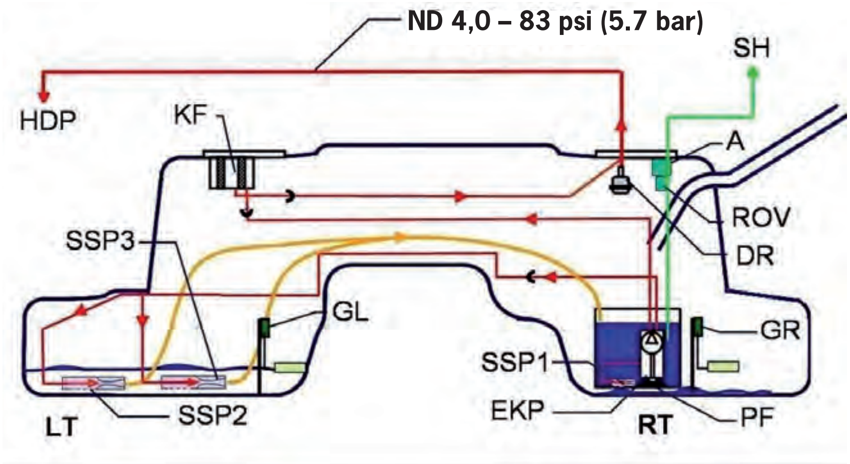
The procedures for checking the fuel pressure, holding pressure and delivery rate of the electric fuel pump are described in the PIWIS information system. Observe the relevant safety instructions when working on the fuel system.



AB	Degassing tank
AKF RoW	Active carbon filter Rest of World
AKF ORVR	Active carbon filter, USA vehicles with ORVR
LD PL 72	Diagnosis module for tank leaks

Internal design of the fuel tank



RT	Right tank chamber (main chamber)
LT	Left tank chamber (auxiliary chamber)
PF	Pump filter
EKP	Electric fuel pump (demand-controlled)
KF	Fuel filter (lifetime filter)
DR	Fuel-pressure regulator (approx. 83 psi/5.7 bar rel.)
ND	Low-pressure line (approx. 83 psi/5.7 bar) to the high-pressure pump
HDP	To the quantity control valve on the fuel high-pressure pump
SSP1	Sucking jet pump, right (1.0 mm) for fulling the electric fuel pump
SSP2	Sucking jet pump, left (0.42 mm, 80 psi/5.5 bar), fills the pump chamber
SSP3 -	Sucking jet pump, left (0.42 mm, 80 psi/5.5 bar), fills the pump chamber
ROV	Roll-over valve (also used for tank venting and fuel level limitation)
A	Adapter to lower the ROV valve (only for 85 l tank)
SH	Auxiliary heater
GR	Fuel level sensor, right
GL	Fuel level sensor, left

Tank ventilation

The fuel tank is aerated and vented exclusively via the active carbon filter, which acts as an intermediate storage device for any HC emissions. Regeneration of the active carbon filter takes place via the tank vent valve when the engine is running. The active carbon filter is installed behind the wheel housing liner at the rear right. When the engine is running, the system is vented via the electric tank vent valve (in the engine compartment) to the intake system of the engine.

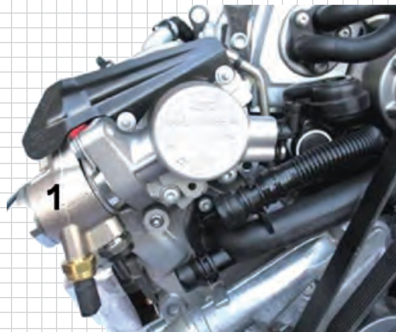
Leakage diagnosis pump (LDP):

On USA vehicles, a diagnosis module for tank leaks (DMTL) is used for the tank leakage test, as in the current sports cars. This module is installed directly at the fresh-air connection of the activated carbon filter.

The function of the diagnosis module for tank leaks corresponds to that of the modules installed in the 9X7 vehicles. A function description can be found in the corresponding Introbook, group 2 in the PIWIS information system.

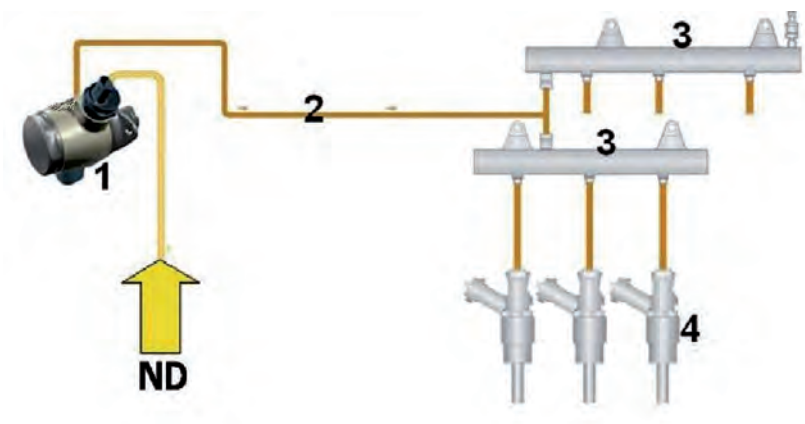
Fuel supply, high-pressure side DFI

In the high-pressure system, a variable pressure is generated when the engine is running. It is regulated between 435 psi (30 bar) and 1740 PSI (120 bar) depending on the engine load.



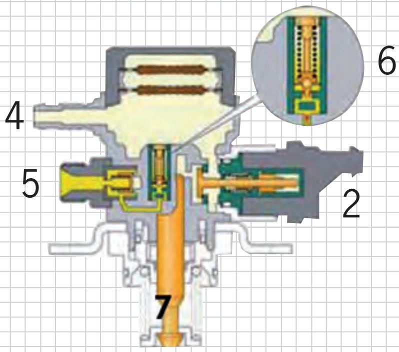
The following components are used:

- Fuel high-pressure pump with quantity control valve for fuel pressure, integrated pressure control valve and fuel pressure sensor for low pressure
- High-pressure fuel line to the fuel rail (distribution pipe)
- Fuel rail (distributor pipe)
- Fuel pressure sensor for high pressure
- Fuel injectors



ND From low-pressure system (max. 83 psi/5.7 bar)
1 High-pressure pump (435 psi/30 to 1740 psi/120 bar)
2 High-pressure line
3 Fuel rail (distribution pipe)
4 Fuel injectors

1 Mechanical drive
2 Quantity control valve (pressure control 435 psi/30 to 1740 psi/120 bar)



1 Fuel pressure sensor, high pressure
2 Lower part of intake manifold

Fuel high-pressure pump

The high-pressure pump is driven with a triple cam on the intake camshaft. To keep the friction between the pump tappet and camshaft as low as possible, the movement is transmitted using roller tappets. The quantity control valve facilitates demand-based regulation of the fuel high pressure between 435 psi (30 bar) and 1740 PSI (120 bar). If the quantity control valve on the high-pressure pump is not activated, the fuel is pumped to the high-pressure fuel system. The pressure control valve is integrated into the fuel high-pressure pump and protects the components against too high a fuel pressure in the event of thermal expansion or malfunctions. It is a spring-loaded valve and opens from a fuel pressure of 2030 psi (140 bar). When the valve opens, the fuel flows from the high-pressure side of the pump back to the low-pressure side.

4 Low-pressure connection
5 High-pressure connection
6 Pressure control valve (2030 psi/140 bar)
7 Pump piston

Fuel pressure sensor, high pressure

The fuel pressure sensor is screwed into the fuel distribution pipe. It measures the fuel pressure in the high-pressure fuel system and sends the signal to the engine control unit.

Signal utilization

The engine control unit evaluates the signals and regulates the high pressure in the fuel rail via the quantity control valve for fuel pressure.

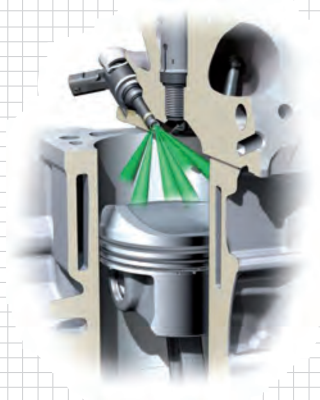
Effects in the event of failure

If the fuel pressure sensor detects that the nominal pressure can no longer be regulated, the fuel pressure regulating valve is permanently activated during compression and is open. The fuel pressure is thus reduced to 72.5 psi (5 bar) of the low-pressure fuel system (emergency operation).

If the fuel pressure sensor fails, the fuel pressure regulating valve is permanently activated during compression and is open. The fuel pressure is reduced to approx. 83 psi (5.7 bar) of the low-pressure fuel system. As a consequence, engine torque and power output are drastically reduced.

Injection strategies

Use of 6-port fuel injectors makes a significant contribution to mixture preparation. The 6-port injectors are designed to ensure optimum homogenization of the fuel-air mixture under any engine operating conditions. The maximum injection time at full throttle is 5 milliseconds. The injection method is designed for operation with homogeneous mixture formation. With the exception of cold start and warm-up, the entire fuel quantity is injected into the combustion chamber during intake.



First engine start

High-pressure stratified charge injection is achieved in the starting phase of the engine. The fuel pressure is increased to 2025 psi (45) – 1450 psi (100 bar). The value for the fuel pressure and the injection strategy depend on the engine temperature.

Warm start

At coolant temperatures over 104° F. (40° C.), map-controlled single injection takes place during the intake stroke.

From 14° F. (-10° C.) to 104° F. (40° C.)

The catalytic converters are heated by means of dual injection (homogeneous split HOSP). The fuel, which is split into two smaller quantities, is injected into the combustion chamber at different times. The time windows for injection are before and after the bottom dead center of the piston. The intake valves are already closed at the time of the second injection.

Below 14° F. (-10° C.)

Single injection with high fuel pressure based on a map stored in the DME control unit takes place.

Ignition system

Ignition coils

The individual ignition coils with integral drivers are controlled by the DME control unit.

Spark plugs

The service intervals and heat ratings of the spark plugs are specified in the country-specific maintenance schedules.

Intake system/Turbocharging

Air filter, air guide

The unfiltered raw air is drawn in under the right headlight, via the air filter housing, the air filter element to the throttle valve control unit (electronic throttle).

The service interval of the air-cleaner element is specified in the maintenance schedule.

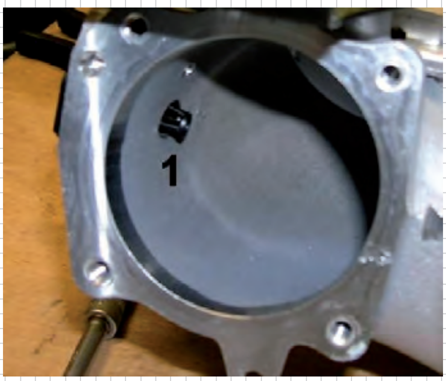
Pressure sensors with temperature sensor

These are sensors for detecting the air mass and the boost pressure.

The main control variables for controlling the boost are

- mass air flow and
- boost pressure.

A total of three sensors with identical functionality are used in this case.



1 Sensor for pressure downstream of throttle valve and intake air temperature

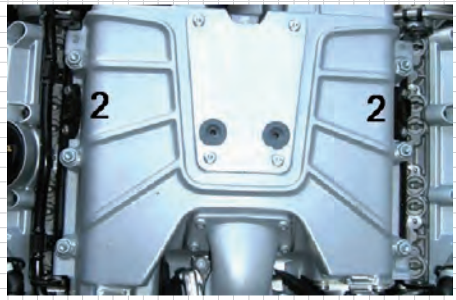
The first sensor is located downstream of the throttle valve control unit and measures the pressure downstream of the throttle valve as well as the intake air temperature. The intake air temperature sensor is a temperature sensor with negative temperature coefficient (NTC).

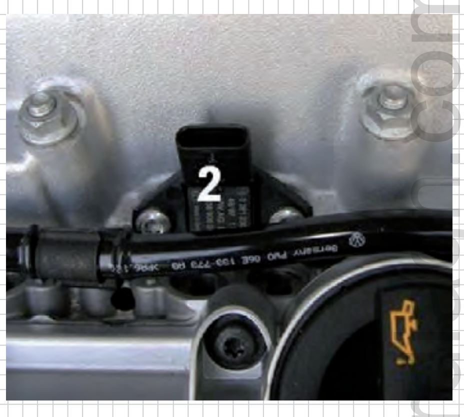
Signal utilisation

The signal is used to calculate the required position of the bypass valve in advance. This is necessary for regulating the desired intake manifold pressure (boost pressure). The required position of the bypass valve depends greatly on the pressure level upstream of the air-charging module.

2 Boost pressure and intake manifold temperature sensor

Two additional sensors are located in the air-charging module and measure the pressure (or boost pressure) and the air temperature downstream of the charge-air cooler of each cylinder bank.





Boost pressure and intake manifold temperature sensor.

Signal utilization

The two boost pressure sensors are used to regulate the boost pressure at the required value. The total mass air flow is also calculated in the DME control unit from these input signals. The mass air flow is an important input value of torque-based engine control, which determines the injection quantity, injection timing and ignition timing angle.

The intake air temperature sensor signal is also required:

- For activation of the pump for coolant run-on. If the temperature difference for the charge air upstream and downstream of the charge-air cooler is less than 46° F. (8° C.), the coolant pump is activated.
- For plausibility checking of the coolant pump. If the temperature difference for the charge air upstream and downstream of the charge-air cooler is less than 36° F. (2° C.), a fault in the pump is assumed. The Check Engine light (MIL) is switched on.

Effects in the event of signal failure

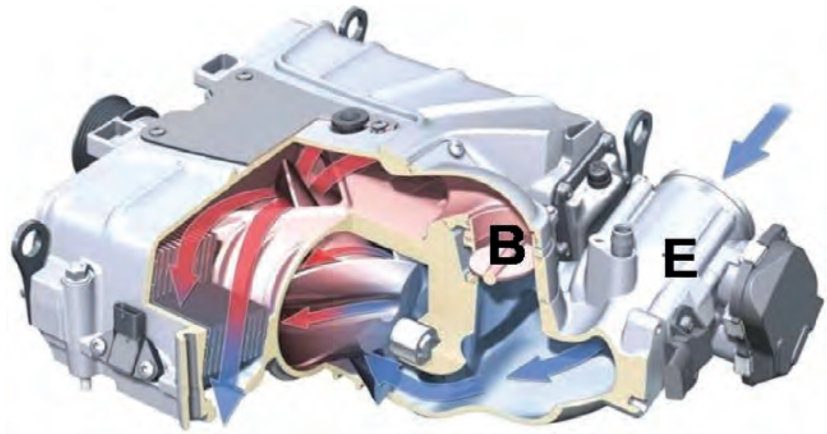
Failure of the intake manifold pressure sensor means that regulation of the boost pressure is not optimal, which can be experienced by the driver in the form of uneven acceleration. Boost pressure sensor failures lead to the mixture composition not being adapted across the entire load/engine speed range, which in turn has a negative impact on emissions. The Check Engine light (MIL) is therefore switched on in the event of a failure. At the same time, a fault entry is made and there is a switch to alternative data.

Load-dependent boost pressure control

Control of the air flow and boost pressure

The supercharger is driven full-time via the second groove of the belt pulley. If there were no boost pressure control available, the supercharger would always generate the maximum air flow and therefore also the maximum achievable boost pressure for the respective speed. However, as charge air is not required under all operating conditions, this would result in excessive air build-up on the pressure side of the blower. This in turn would lead to unnecessary engine load. It must therefore be possible to control the boost pressure.

E Throttle valve (electronic throttle)
B Bypass valve



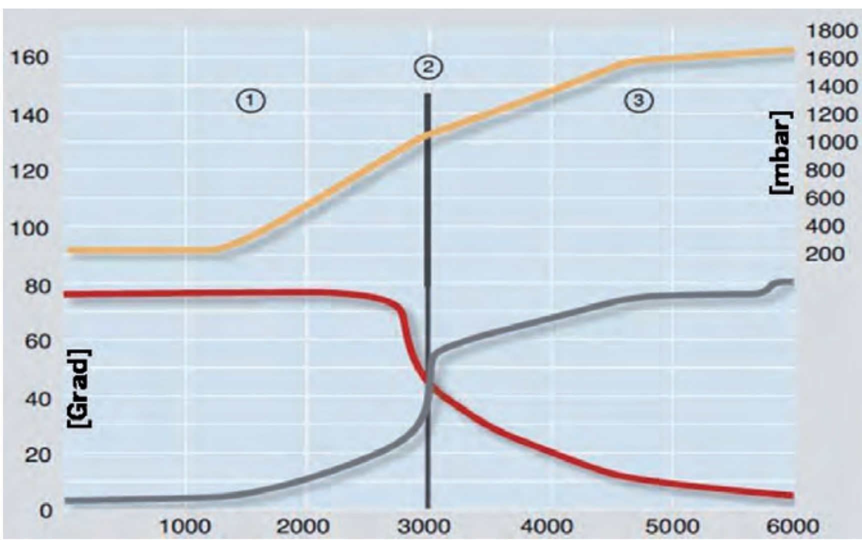
The bypass valve control unit is used for boost pressure control. It is screwed into the air-charging module and connects the pressure side of the compressor with the intake side. When the bypass valve is opened, some of the delivered air volume is returned to the intake side of the supercharger via the open bypass. The function of the bypass valve is similar to a wastegate valve on a spark-ignition engine with turbocharger.

The bypass valve control unit works in combination with the throttle valve control unit (electronic throttle). With this control, particular importance was attached to achieving throttle-free operation as much as possible along with superior power development. The division of work between the two valves is shown in the illustration.

In the partial-load/intake area, the bypass valve is open (no boost pressure) and the throttle valve control unit (electronic throttle) assumes load control.

In the boost pressure area, the bypass valve assumes load control, as the electronic throttle is fully open.

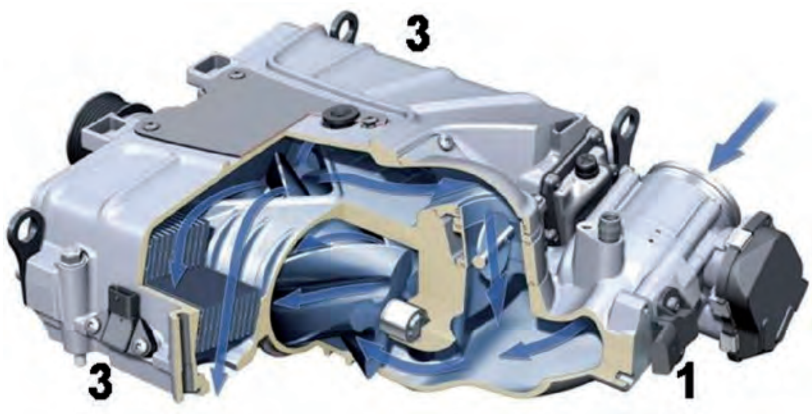
Yellow	Intake manifold pressure (boost pressure) in millibar
Red	Bypass valve position in degrees
Grey	Electronic throttle position (opening angle) in degrees
1	Intake area
2	Ambient pressure
3	Boost area



Load conditions

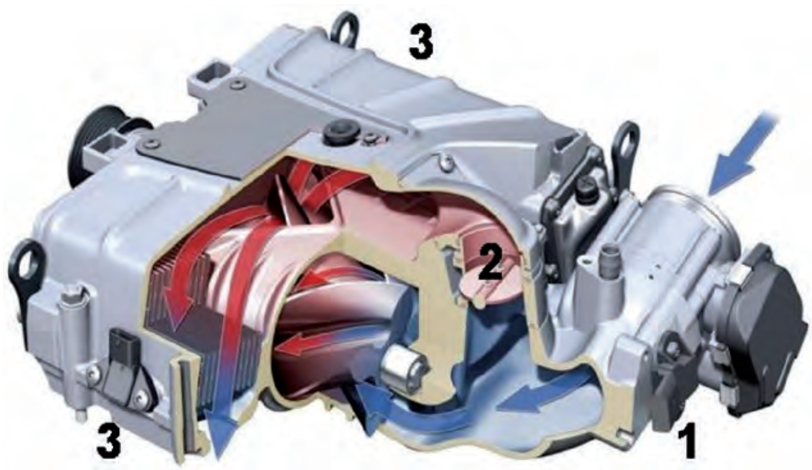
Idle speed, partial load, overrun

At idle speed, in the partial load range and in deceleration, some of the delivered air volume is returned to the intake side through the open bypass valve. This is controlled by the electronic throttle position.



Full throttle

At full throttle, the air flows directly to the engine via the supercharger and charge-air cooler with the electronic throttle open. The desired boost pressure is now regulated by the bypass valve.



1 Intake manifold pressure and intake air temperature sensor
2 Bypass valve
3 Boost pressure and intake manifold temperature sensor

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Further information is provided in the brochure "Cayenne S Hybrid Training Information", section 1 "Combustion engine".

Bypass valve control unit

Tasks

- Regulation to the boost pressure specified by the DME control unit
- Limitation of the maximum boost pressure to 28 psi (1.9 bar) absolute pressure

B Installation position of the bypass valve

Potentiometer for bypass valve

This component detects the current bypass valve position. It is installed inside the cover of the adjuster housing. Its output voltage range is between 0.5 and 4.5 V. The potentiometer is designed to be resistant to electromagnetic radiation (EMC).

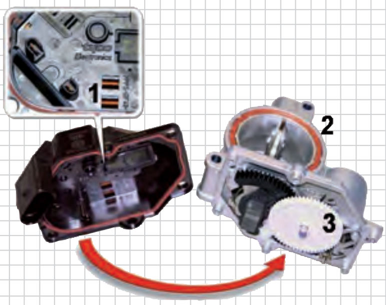
Signal utilization

The feedback signal from the bypass valve position is used to define the regulator input values. It is also used to determine the adaptation values.

Effects in the event of signal failure

The valve is de-energized and moves spring-loaded to the open stop. The fault is irreversible for one driving cycle. No boost pressure is built up in this case. Neither the full power nor the full torque are available.

The component is subject to OBD, which means that the Check Engine light (MIL) is switched on in the event of a failure.

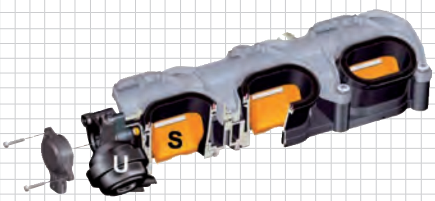


1 Position sensor
2 Bypass valve
3 Servo motor

Intake manifold flaps

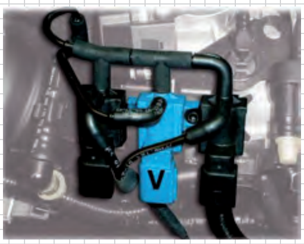
To improve internal mixture formation, the 3.0 l V6 DFI engine uses intake manifold flaps (S). They are located in an intermediate flange between the air-charging module and cylinder head.

The intake manifold flaps have the task of setting the air in the combustion chamber in a charge motion, thus achieving optimum mixture formation.



Valve for intake manifold flap

The intake manifold flaps, which are secured on a common shaft, are actuated by a vacuum unit (U).The required vacuum is applied by the valve (V) for the intake manifold flap. The engine control unit actuates the valve for the intake manifold flap according to the map.

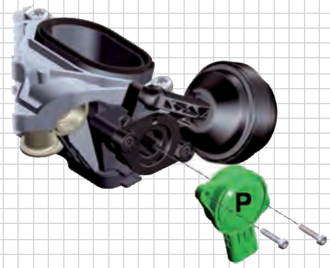


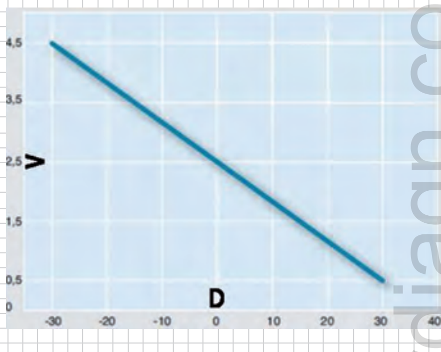
Effects in the event of failure

No vacuum is applied if a valve is not actuated or is faulty. In this state, the intake manifold flaps close the duct in the cylinder head via the spring force of the vacuum unit The engine power is thus reduced.

Potentiometer for intake manifold flaps

The position of the intake manifold flaps is monitored by one sensor (P) per cylinder bank. The sensors are integrated directly in the flange of the vacuum unit. They are contactless torque angle sensors, which operate according to the Hall sender principle. They generate a voltage signal, which is evaluated by the engine control unit. The magnitude of the signal voltage depends on the opening angle of the intake manifold flap.





V Voltage signal in volts
D Torque angle in degrees

Signal utilisation

The signal monitors the position and is used for diagnostic purposes.

Effects in the event of signal failure

The component is subject to OBD. Incorrect positioning will be detected via diagnosis. The Check Engine light (MIL) is switched on in the event of a failure.
The engine power is reduced.

Exhaust system

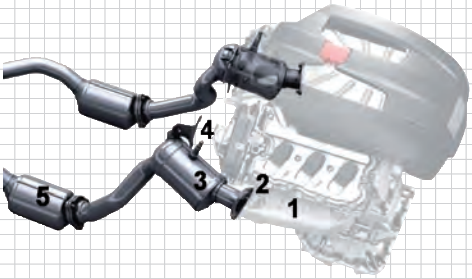
1 Exhaust manifold
2 Main catalytic converter (ceramic substrate)
3 Front muffler
4 Intermediate muffler
5 Main muffler
6 Tailpipe cover

The exhaust system not only ensures that pollutants are cleaned from combustion exhaust gases, it also has a significant effect on the acoustics of the vehicle.
The exhaust system is made from stainless steel to be able to withstand the extreme conditions such as mechanical loads, severe changes in temperature and other environmental influences. Exhaust gases flow via two exhaust tracts from the respective exhaust manifold via the main catalytic converters, the front mufflers and the intermediate muffler to the rear muffler. They then escape via the tailpipe covers at the left and right.

Emission control

As a result of combustion of the fuel-air mixture, small quantities of pollutants (nitrogen oxides (NOx), hydrocarbons (HC), carbon monoxide (CO) and soot particles) are produced in addition to CO_2 and water vapor. The Cayenne S Hybrid has two close-coupled main catalytic converters in order to achieve compliance with the strict worldwide emission standards.

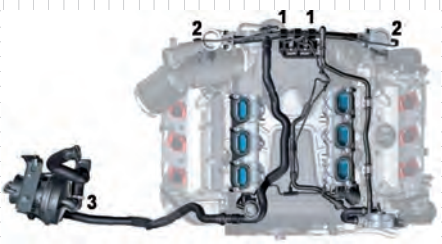
This arrangement achieves faster heating up to the optimum operating temperature as well as a lower heat loss during the Start Stop phases.



1 Exhaust manifold
2 Oxygen sensor (LSU 4.9) upstream of catalytic converter
3 Main catalytic converter (ceramic substrate)
4 Oxygen sensor (LSF 4.2) downstream of catalytic converter
5 Front muffler

Secondary air injection

In order to achieve compliance with the worldwide emission limits, the models Cayenne S Hybrid (worldwide), Cayenne S (in EU5 markets) and Cayenne Turbo (EU5 markets) feature secondary-air injection. The secondary-air system provides faster heating of the catalytic converters and a reduction in exhaust emissions. For this purpose, air is injected into the exhaust tract behind the exhaust valves for a defined period after the engine cold start. The uncombusted hydrocarbons and carbon monoxide either contained in the exhaust gas or deposited in the catalytic converter then react with the oxygen in the air. The heat that is released means that the operating temperature of the catalytic converter is reached more quickly.



1 Electric vacuum control valves bank 1 + 2 for secondary air
2 Combination valves 1 + 2 for secondary air
3 Secondary-air pump

Differences between Europe/USA

To comply with the Euro 5 emission standard, two electric change-over valves (1 - Secondary-air injection valves) are used.
To comply with the ULEV II emission standard, USA vehicles also have a pressure sensor for secondary air pressure. It is installed directly in the division between the secondary-air line and the cylinder banks.

Secondary-air injection valves

System test for engines complying with Euro 5 emission standard

For engines with Euro 5 classification, oxygen sensor-based secondary-air diagnosis is used to test the system. The secondary air mass is calculated by the engine control unit during injection of the secondary air based on the changing oxygen content. However, diagnosis is not performed during the normal secondary-air operating time, as the oxygen sensors reach their operating temperature too late. The system is activated separately for diagnosis. Testing is carried out in several phases.

Measurement phase

The secondary-air pump is activated and the secondary-air valves (combination valves) are opened. The engine control unit evaluates the oxygen sensor signals and compares them with the threshold values. If the threshold values are not reached, a fault is recorded.

Offset phase

After the secondary-air pump is switched off, the quality of the mixture pilot control is evaluated. If there is a significant deviation in the calculated value, the result of the secondary-air diagnosis is discarded. It is assumed that there is a fault with the mixture formation in this case.

System test for engines complying with ULEV II emission standard

Here, the test must be carried out during the warm-up phase for the catalytic converters. However, the oxygen sensors do not reach operating temperature quickly enough. An additional pressure sensor (secondary-air pressure sensor) is therefore used for diagnosis. It is used to carry out pressure-based secondary-air diagnosis. In this system, the signal is evaluated by the secondary-air pressure sensor in the engine control unit. The injected air quantity is deduced from the pressure level.

1 Electric vacuum control valves bank 1 + 2 for secondary air
2 Combination valves, bank 1 + 2 for secondary air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3 Power transmission

General

Like the other Cayenne models, the Cayenne S Hybrid features the new 8-speed Tiptronic S transmission. The transmission was adapted to suit hybrid-specific driving modes as follows:

- Additional electric oil pump for increased volume flow
- Modified gearshift setup and shifting characteristic
- Modified torque converter lockup clutch
- Enhanced transmission control unit functionality

Auxiliary oil pump

As the conventional oil pump is powered by the torque converter in an automatic transmission, oil pressure is only generated when the combustion engine is running. However, in a hybrid vehicle, the transmission must also be supplied with oil pressure when the combustion engine is not active, as only then can gearshifts be carried out.

The Cayenne Hybrid therefore features a powerful oil pump installed under the converter bell housing. The oil pump is driven by an electric motor, which is activated by the transmission control unit. The brushless DC motor consists of a rotor with four pairs of permanent magnets and a stator with six solenoid pairs.

In terms of installation position and function, this motor is similar to the motor in the Start Stop system; the increased number of magnet pairs produces a higher torque and thus a higher delivery rate.

Using the position sensors, the rotational speed is used to determine whether there is a fault. If this is the case, start-up of the ATF pump by the combustion engine is requested from the engine control unit via the transmission control unit.

Stator with six solenoid pairs and three position sensors

Rotor with four pairs of permanent magnets

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Torque converter lockup clutch	134
Enhanced transmission control unit functionality	134

Gearshift setup/shifting characteristic

The spread over 8 gears also allows better exploitation of the torque advantage of the synchronous motor, particularly in the lower transmission ranges when driving solely on electric power and during boosting. The transmission is mounted directly on the hybrid module and is important for efficient and comfortable power transmission in all hybrid-specific driving modes, e.g. during recuperation. The shifting characteristic was adapted to increase recuperation performance during the recovery of brake force through adaptation of the gear-changing speeds (downshifts) or to achieve a comfortable restart of the combustion engine when driving solely on electric power with reduced shifting frequency. The special adaptation of the 8-speed Tiptronic ensures an optimum gearshift strategy during boosting with additional drive torque from the electric motor.

Torque converter lockup clutch

The torque converter lockup clutch in the converter of the automatic transmission was adapted to the high torque in the boost phases and thus has a high torque capacity even at very low speeds.

Enhanced transmission control unit functionality

The enhanced transmission control unit functionality with modified shift maps for the Cayenne S Hybrid facilitates the control of power transmission in the hybrid-specific driving modes and ensures optimum efficiency. In addition, the control coordinates the interaction between the electric oil pump and the existing mechanical pump unit.


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4 Chassis

General

The Cayenne S Hybrid is equipped as standard with a steel spring suspension, which meets the high requirements for performance, driving pleasure and off-road usability. The Cayenne Hybrid can essentially be equipped with the same optional equipment as the Cayenne S, though not all options are possible due to the drive strategy.

Overview

Chassis and options ● = Standard ○ = Option - = Not available	Cayenne S Hybrid
Steel spring suspension	●
Steel spring suspension with Porsche Active Suspension Management (PASM)	○
Air suspension with levelling system and ride-height adjustment incl. PASM	○
Servotronic	●
Porsche Dynamic Chassis Control (PDCC)	-
Porsche Torque Vectoring Plus (PTV Plus)	-

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Brake booster on Cayenne S Hybrid 140
Brake system on Hybrid (recuperation) 142

Note:
The hybrid-specific chassis components are described below. The Service Information Technik "Cayenne" describes the standard equipment and options.

Steering on Cayenne S Hybrid

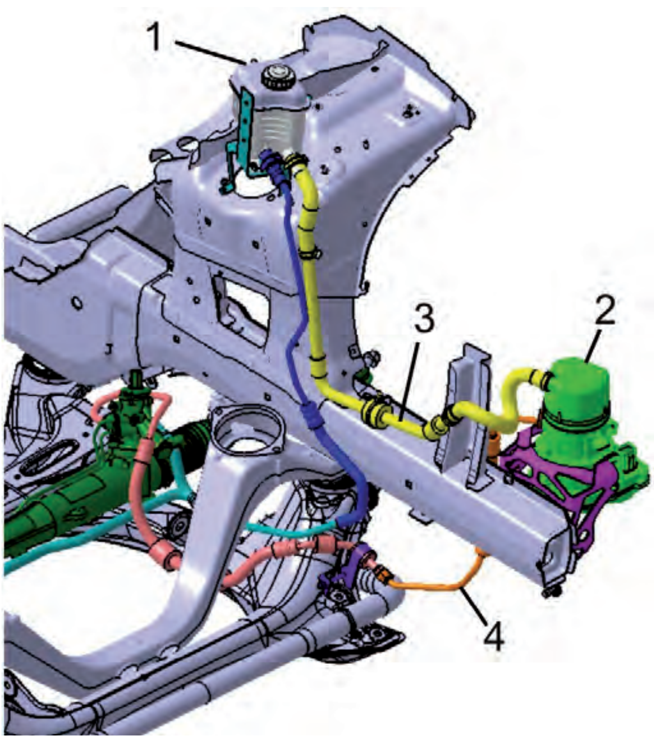
Since power assistance is also required for the steering when driving with electric power, the Cayenne S Hybrid is equipped with electro-hydraulic power assistance. The required hydraulic pressure is provided by a demand-controlled hydraulic pump, which is powered via the 12 V vehicle electrical system.

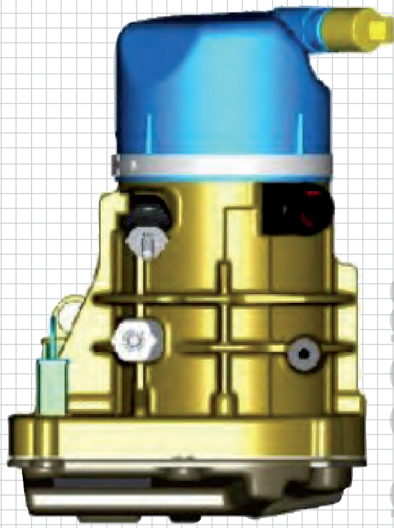
Steering gear

The Cayenne S Hybrid comes with a variable rack-and-pinion steering gear with hydraulic support and Servotronic valve as standard. The steering ratio is i = 16.7:1 in the center position and becomes more direct as the steering angle increases (up to i = 13.3:1). For further adaptation of the steering dynamics, the effective piston diameter was reduced along with the hydraulic control design.

Steering hydraulics

The scope of the steering hydraulics includes the reservoir (1), electric pump (2), suction line (3) and pressure line (4). The system is filled with Pentosin.



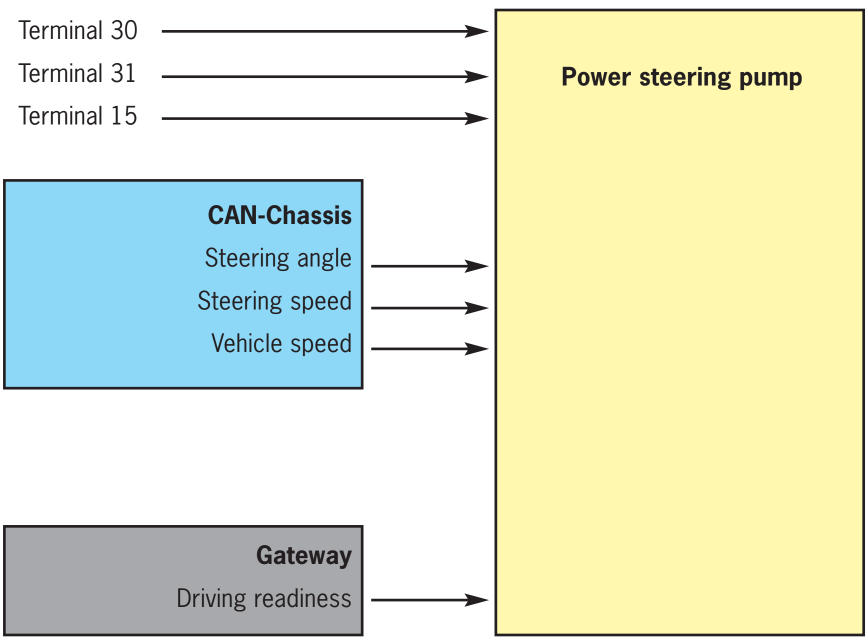


Hydraulic pump

The hydraulic pressure is delivered by an electrically driven gear pump integrated in the front left wheel housing. The demand-controlled pump only generates the energy required for power assistance in response to a steering command from the driver and otherwise remains in standby mode, e.g. when driving straight ahead. This contributes to a reduction in fuel consumption of more than 80% compared with purely hydraulic systems. The electrification of the unit means that the function is guaranteed even in driving modes with the combustion engine switched off. The Servotronic thus also functions when maneuvering in purely electric mode.

The pump drive power is controlled for optimum fuel consumption according to the vehicle speed, steering angle and, most importantly, the steering angle dynamics. Efficient control means that cooling of the power-steering fluid is not required.

Control unit structure



The system adapts to the requirements of the driving situation for efficient energy usage and delivers the boost pressure currently required for steering. It starts as soon as terminal 15 is switched on and the drive unit sends the driving readiness information.

The vehicle speed, steering angle and steering angle speed signals are evaluated in order to determine the defined speed for delivery of the required hydraulic pressure or flow using a programmed map.

- Power assistance failure
- Power assistance fault
- Power assistance malfunction

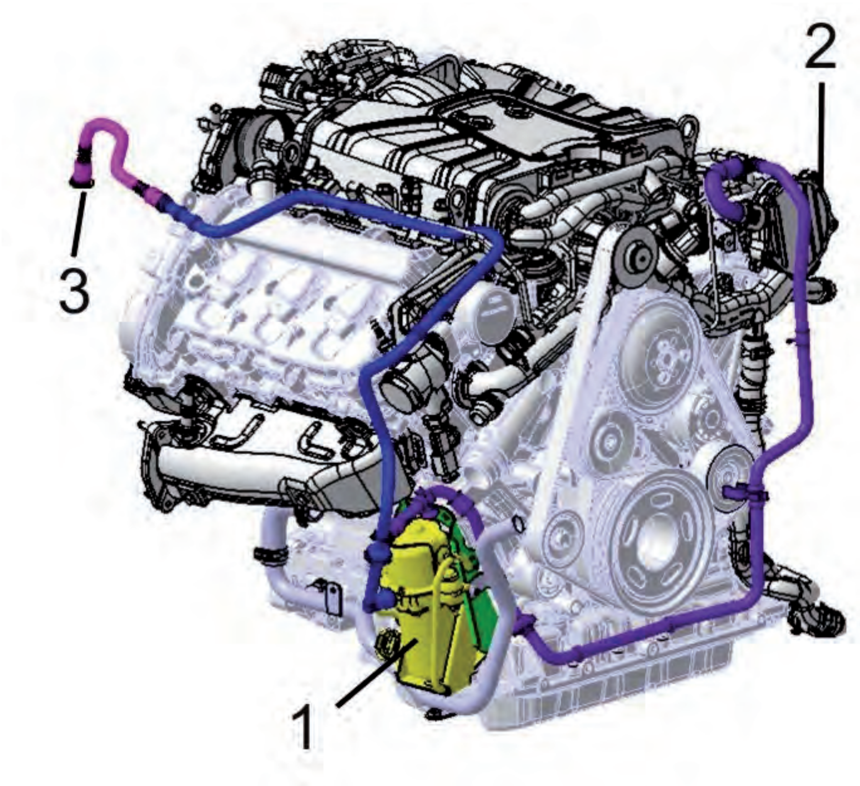
Diagnosis, safety

The control unit diagnoses its internal components and checks the incoming CAN signals for plausibility. If the vehicle speed or steering angle sensor data is not received, the missing value is replaced by a predefined basic value in emergency operation mode in order to guarantee basic power assistance. In this emergency mode, higher forces are sometimes required for steering. For all faults, the steering wheel symbol and corresponding text message are displayed in the instrument cluster.

Brake booster on Cayenne S Hybrid

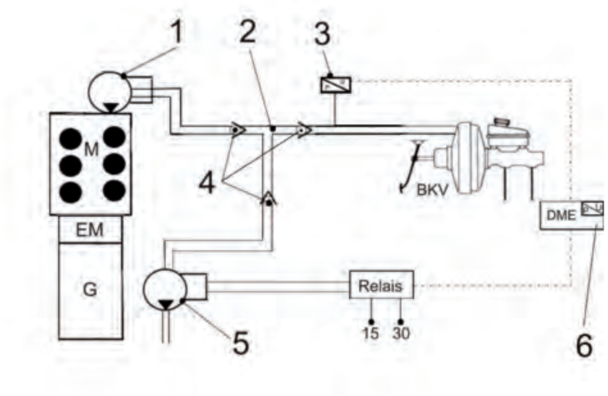
The Cayenne S Hybrid uses an additional electric vacuum pump, which can supply the required brake pressure even when the engine is switched off. This is the case when the Cayenne S Hybrid drives on electric power only, coasts or is in Auto Start Stop mode.

Design



1 Electric vacuum pump
2 Mechanical vacuum pump
3 To the brake booster

Schematic diagram



1	Mechanical vacuum pump
2	Vacuum line
3	Pressure sensor
4	Check valves
5	Electric vacuum pump
6	DME control unit with integrated pressure sensor
BKV	Brake booster
M	Combustion engine
EM	Electric motor
G	Transmission

Function

When the combustion engine is in operation, the vacuum for the brake booster is supplied by the mechanical vacuum pump (1). When the combustion engine is switched off, the electric vacuum pump is switched on as required depending on the vacuum conditions.

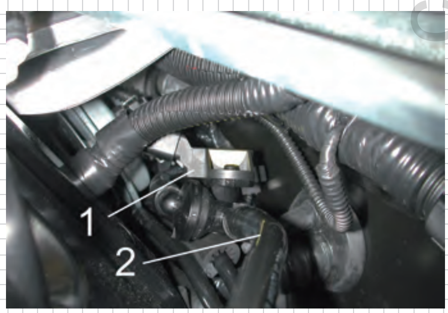
The pressure sensors installed in the vacuum line and DME control unit record the current pressure in the brake booster as well as atmospheric pressure. If the vacuum detected in the brake booster is too low, the DME control unit switches on the vacuum pump via a relay. The vacuum range is between 550 mbar and >750 mbar.

Diagnostics

Within the framework of diagnosis, the vacuum supply is continuously checked and appropriate measures are initiated if necessary.

If, for example, the vacuum level does not increase by at least 200 mbar within 10 seconds despite activation of the vacuum pump, the combustion engine is not switched off again. If the vehicle is driving in electric mode, the combustion engine is switched on again immediately. In this situation, the yellow Hybrid warning lamp is switched on.

If the required vacuum is not reached again (e.g. as a result of leakage), the red brake warning light is switched on.



1 Vacuum sensor

2 Vacuum line

Brake system on Hybrid (recuperation)

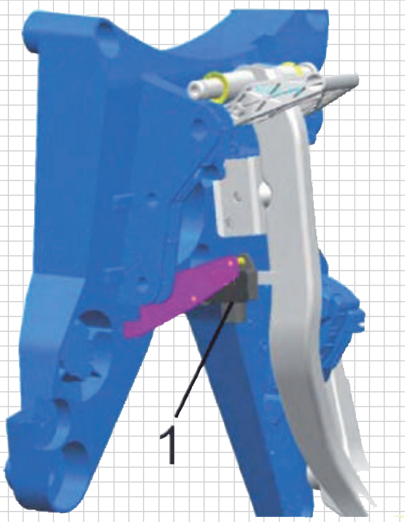
A special feature of the Cayenne S Hybrid is the highly efficient brake system, as it recovers part of the usually otherwise lost braking energy and renders it reusable for the drive. In addition to the hydraulic brake system on the front and rear axle used in the Cayenne S, which is actuated via a tandem brake master cylinder, the electric machine of the hybrid module contributes some of the braking performance in generator mode. The electric machine uses the mechanical kinetic energy from the moving vehicle's drive shaft here, whereby the rotor rotating with the shaft induces an electric current in the stator windings. The current is stored as electrical energy in the traction battery.

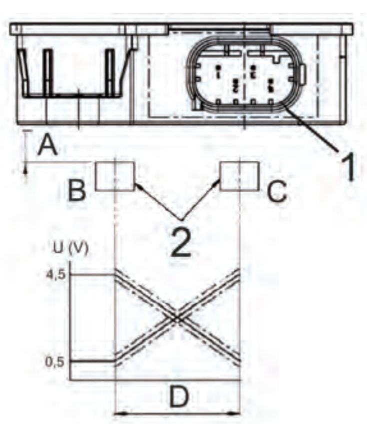
Brake pedal sensor

The brake pedal sensor mounted on the pedals detects the degree of deceleration desired by the driver, which is duly input as a parameter in the operating strategy in order to generate braking torque in the electric machine. Recuperation is thus possible in the free travel area (pedal travel without conventional braking force) of the brake pedal before hydraulic brake pressure can actually be generated. The free travel was increased by 4 mm for more precise control.

Function

The brake pedal has a permanent magnet, which passes the pedal sensor when the brake is actuated. The sensor contains two Hall sensors within a measuring range, which cause a corresponding output voltage to be produced when the magnet is passed (Hall effect). Recuperation is controlled using this signal.





1 Brake pedal sensor
2 Permanent magnet
A Distance from magnet to sensor
B Start measuring range (brake pedal final position)
C End measuring range
D Measuring range

!

To guarantee optimum recuperation, the installation position of the pedal sensor must be strictly observed.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5 Body

General

The Cayenne S Hybrid has the same bodyshell as all Cayenne models. An additional holder for the power electronics is installed on the front left side member (replacing the air filter holder).

Safety instructions

All work on hybrid vehicles must be performed exclusively by appropriately qualified staff.

Please refer to the relevant safety regulations before commencing any body repairs (see Workshop Manual).

The high-voltage system must be de-energized before starting work close to high-voltage components or high-voltage lines using metal cutting, forming or sharp-edged tools or heat sources, e.g. welding, soldering, hot air or thermal bonding. De-energizing is also necessary before performing work with a frame bench/ straightener.

Please refer to the Workshop Manual for information on the work for which it is necessary to de-energize the high-voltage system.

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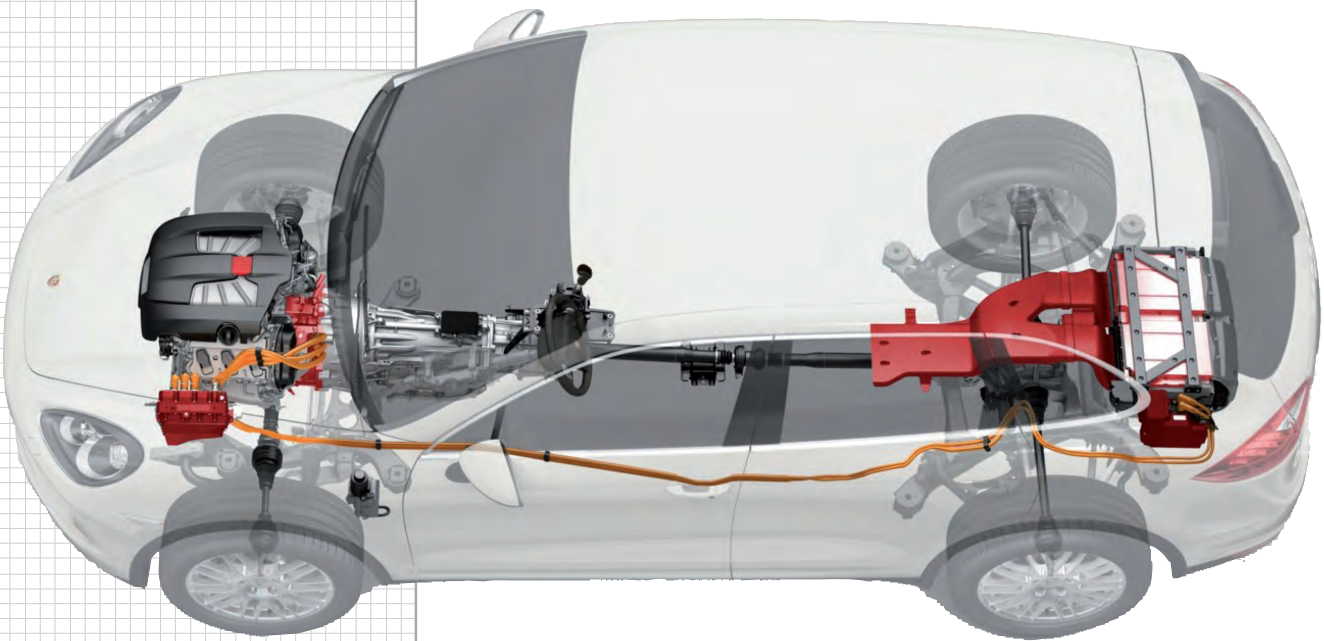
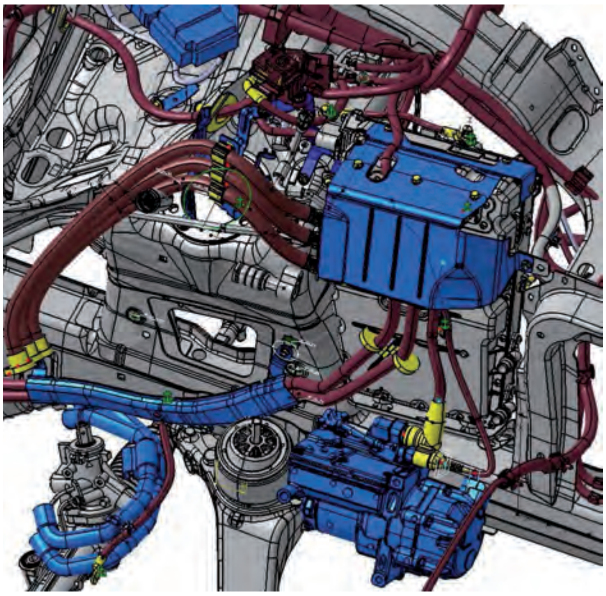
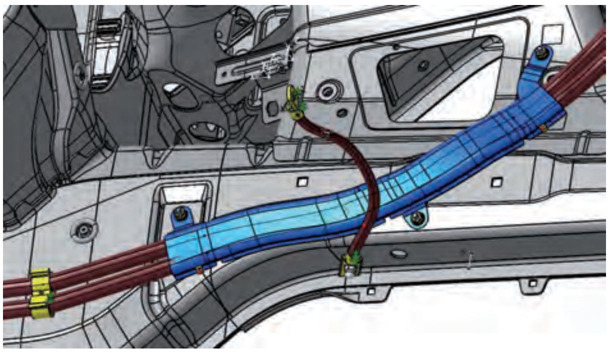
Routing of the high-voltage line



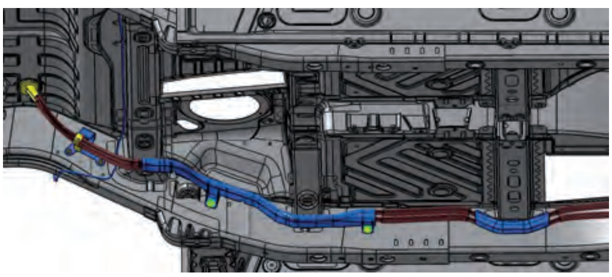
The high-voltage line runs along the body from the power electronics in the engine compartment to the high-voltage battery at the rear of the vehicle.



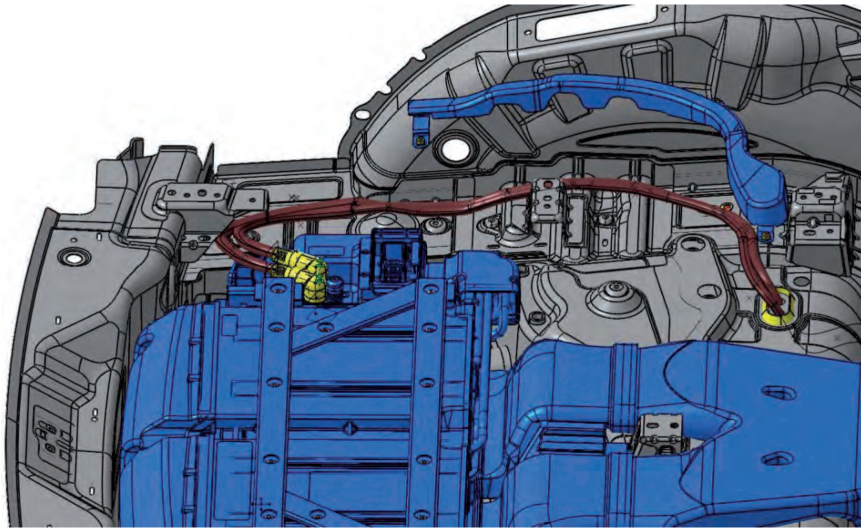
The high-voltage line runs from the power electronics on the left of the engine compartment along the inside of the left side member.



The high-voltage line continues to run along the left side member.



The high-voltage line continues to run under the vehicle floor along the left member until it reaches the rear of the passenger compartment. The line is covered in places and is secured to the body with clips and flange nuts.



The high-voltage line then enters the passenger compartment. The high-voltage line runs on the luggage compartment floor along the left wheel housing as far as the high-voltage battery.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6 Body equipment, exterior

General

The Cayenne S Hybrid has the same exterior design as all Cayenne models.

Safety instructions

All work on hybrid vehicles must be performed exclusively by appropriately qualified staff.

Please refer to the respective safety regulations before commencing any body repairs (see Workshop Manual).

The high-voltage system must be de-energized before starting work close to high-voltage components or high-voltage lines using metal cutting, forming or sharp-edged tools or heat sources, e.g. welding, soldering, hot air or thermal bonding. De-energizing is also necessary before performing work with a frame bench/straightener.

Please refer to the Workshop Manual for information on the work for which it is necessary to de-energize the high-voltage system.

Exterior differences

On the Cayenne S Hybrid, the LED daytime running lights are installed in the horizontal front light units on the upper edge of the side air intakes.

The left and right front fenders feature a chrome-colored “hybrid” logo.

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7 Body equipment, interior

General

The Cayenne S Hybrid has the same interior as all Cayenne models, offering new functionality as well as improved ergonomics and comfort.

Safety instructions

All work on hybrid vehicles must be performed exclusively by appropriately qualified staff.

Please refer to the respective safety regulations before commencing any body repairs (see Workshop Manual).

! Please refer to the Workshop Manual for information on the work for which it is necessary to de-energize the high-voltage system.

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8 Heating and air conditioning

General

The Cayenne S Hybrid has many design features that utilize the high-voltage system in the vehicle. For example, the Cayenne S Hybrid has neither a 12 V generator nor an electric 12 V starter, as these components are replaced by the hybrid module, which is operated at 288 V.

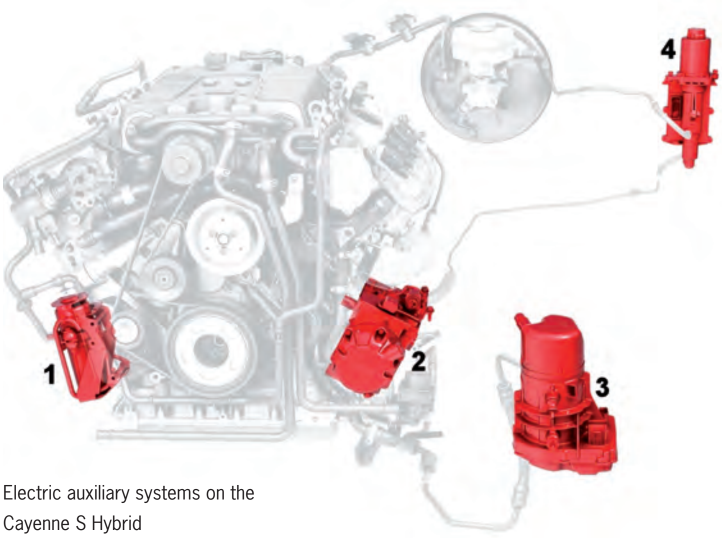
The Cayenne S Hybrid can be driven purely on electric power thanks to its full parallel hybrid drive. After the combustion engine is switched off, various components, which are normally powered by the combustion engine, must be powered electrically.

The safety instructions must be observed during work on the Cayenne S Hybrid. All work on hybrid vehicles may only be performed by qualified staff. Further information is provided in the "Cayenne S Hybrid Training Information" and in the "PIWIS Information System".

Electric auxiliary systems

The Cayenne S Hybrid has the following electric auxiliary systems:

- Electrohydraulic servo pump
- Electric vacuum pump (brake booster)
- Spindle actuator (decoupler control)
- Electric air-conditioning compressor



Electric auxiliary systems on the Cayenne S Hybrid

1 Electric vacuum pump
2 Electric air-conditioning compressor
3 Electrohydraulic servo pump
4 Spindle actuator

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Special features	**156**
Technical data	**156**
Overview of air-conditioning compressor	**156**
Electric drive	**157**
Scroll compressor	**158**

Goals

- Air conditioning function even when the combustion engine is switched off through electrical operation of the air-conditioning compressor
- Reduced fuel consumption through demand-based regulation of the air-conditioning compressor

Special features

The air-conditioning compressor is powered electrically to allow vehicle air conditioning even when the combustion engine is switched off and is an exception among the aforementioned electrically powered components, as it has a different

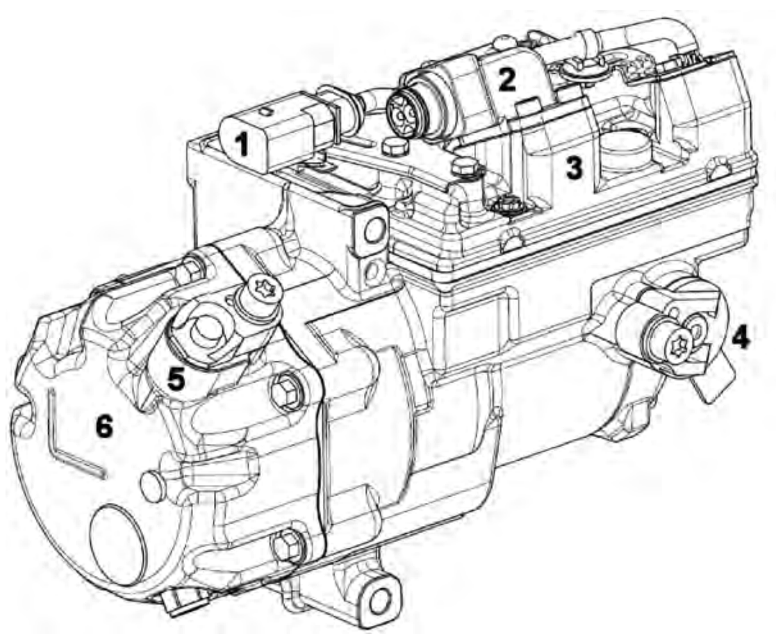
- nominal voltage (288 V)
- and internal design

compared with conventional air-conditioning compressors.

Technical data

Maximum cooling output	7.6 kW
Maximum power consumption	4.05 kW
Operating voltage	288 V
Operating speed range	800 - 8,600 rpm

Overview of air-conditioning compressor



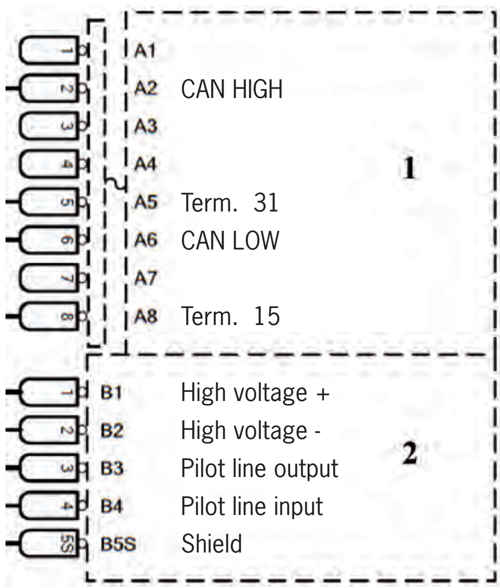
1 Electrical connection CAN-MMI and 12 V power supply
2 Electrical connection, high-voltage lines, shielding line and pilot line
3 Inverter and driver (driver electronics)
4 Low-pressure connection
5 High-pressure connection
6 Compressor housing

Electric drive

Unlike conventional air-conditioning compressors, the scroll compressor used here does not run with the combustion engine, but is instead only operated via an electric motor as required. In other words, the compressor only produces a power loss when cooling power is actually to be produced. This means:

- Reduced load on the vehicle electrical system electronics due to low current consumption
- Less wear on the air-conditioning compressor

This results in additional fuel consumption savings.



1 Terminal voltage connections
2 Inverter connection with shielding line and pilot line

The scroll compressor is supplied with a voltage of 288 V DC from the power electronics of the high-voltage system via a high-voltage cable to drive the integrated electric motor.

The energy required to drive the brushless direct-current motor (see Group 2, section Hybrid Technology, Principles) is converted by the inverter from DC voltage (288 V) to a 3-phase AC voltage (alternating voltage) of 280 V. The three-phase motor is supplied with power via three phases and drives the scroll compressor wheel, which compresses the refrigerant.

The driver electronics are, like the inverter, integrated in the upper section of the compressor housing. They are supplied with a 12 V power supply, which is switched via terminal 15, and receive commands from the air-conditioning control unit via the MMI bus.

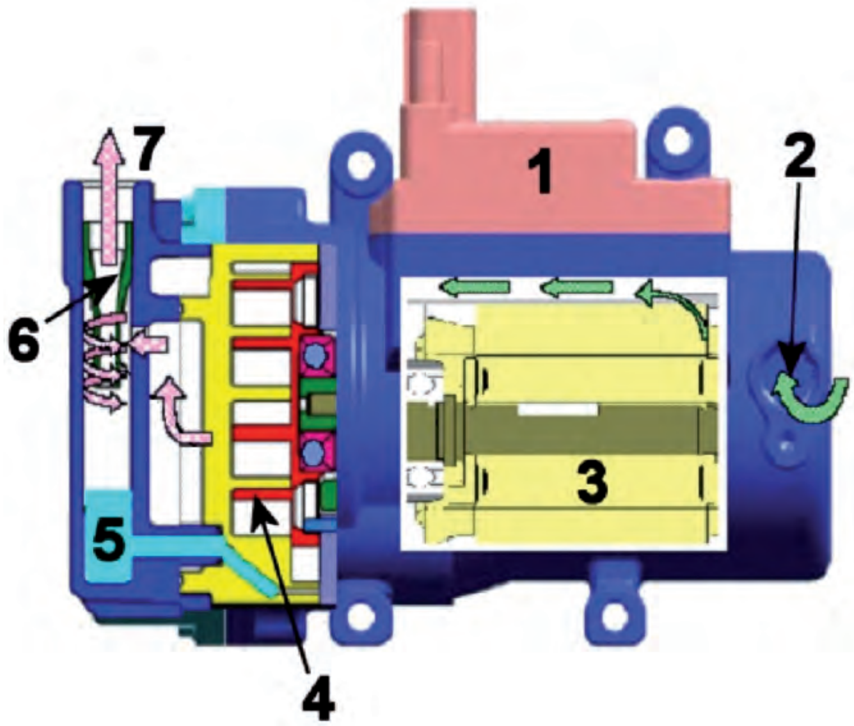
The air-conditioning compressor is diagnosable.

1 Inverter
2 Low-pressure connection (inlet)
3 Brushless direct-current motor
4 Scroll compressor wheel
5 Oil collection chamber
6 Venturi oil separator
7 High-pressure connection (outlet)

Scroll compressor

The air-conditioning compressor compresses the refrigerant with the aid of a scroll compressor instead of the swash plate that is used with conventional air-conditioning compressors.

The scroll compressor consists of two interleaved scrolls, one of which is fixed while the other moves in a circular motion within the fixed scroll. The scrolls almost come into contact with one another many times and form multiple continuously increasing and decreasing chambers within the scrolls. The refrigerant to be compressed passes through these changing pockets until it reaches the center of the compressor. Here, the compressed refrigerant is then discharged and fed to the refrigerant circuit in a pressurized state.



To separate the ND8 oil, an oil separator that functions according to the Venturi principle is used at the high-pressure outlet.

The rest of the air-conditioning system is based on the conventional design.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9 Electrics and electronics - High-voltage safety

Foreword

During the development of the hybrid drive concept, all available options were successfully implemented to construct safe vehicles for the user and workshop personnel. During maintenance and repair, knowledge of the integral safety mechanisms helps protect maintenance personnel and third parties as well as perform work on high-voltage vehicles safely.

These pages highlight the possible dangers and consequences of handling high-voltage components used in the Porsche hybrid drive concept and describes the safety mechanisms that Porsche has integrated in the hybrid drive.

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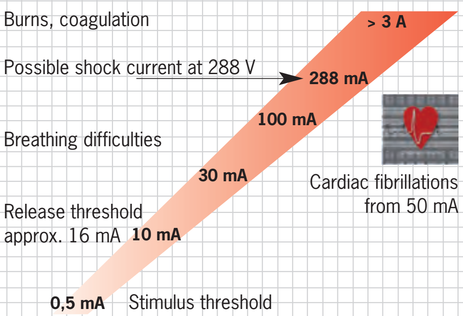
Dangers of working with electrical currents **162**
Actions in the event of an accident involving electricity **165**
Protective measures **168**
Classification of devices into protection classes **177**
Classification of protective measures **178**
Porsche high-voltage safety concept **188**
Measurements on the high-voltage system **197**
Competencies and responsibilities **199**
Consequences of occupational safety breaches **201**

Remaining in the direct vicinity of an activated electric machine or high-voltage system can impair the function of electronic life-support systems. These include:

- Internal analgesic pumps
- Brain pacemakers
- Implanted defibrillators
- Cardiac pacemakers
- Insulin pumps
- Hearing aids

Employees wearing these or similar devices on or inside the body are not permitted to perform work on high-voltage vehicles!



Dangers of working with electrical currents

Electrical current passing through the body

The degree of risk posed by electrical energy not only depends on the level of the electrical current generated from the voltage, but also the exposure time, frequency and route that the current takes when passing through the human body.

In this regard, current that flows through the heart is particularly dangerous, even more so when the heart attempts to follow the frequency of the alternating current. Cardiac fibrillations that can occur even after momentary exposure and at low currents are the direct consequence. The pumping capacity of the heart decreases to zero. A lack of oxygen leads to a loss of consciousness and death within a very short time.

The maximum permitted voltage that people can come into contact with is therefore different for direct and alternating currents. The maximum voltage is 50 V for alternating currents and 120 V for direct currents. On electrical systems that operate with higher voltages, safety measures prevent currents from flowing through the body or switch off the system within a specific time (e.g. < 0.2 s).

Bodily reactions

Sensitivity to the electrical currents depends entirely on the individual. While the perception threshold is usually 0.5 mA, some people claim to feel nothing when exposed to much higher currents. Sensitive individuals and children, however, are able to sense much weaker currents due to the physiological condition of the individual. The following are directly responsible for sensations and the actual flow of current:

- Level of the voltage supplied
- Resistance at the points of entry and exit
- Individual resistance of the body tissue
- Sensitivity of the affected area of the body

The effects of the current flow on people depend heavily on the length of time the current is applied. While exposure to currents below 10 mA does not generally have a damaging effect, even for prolonged periods, currents >200 mA have a harmful effect and cause serious physical reactions if the exposure time exceeds 10 ms.

As a result, maximum release times (e.g. < 0.2 s) are defined for protective measures. The electric shock can then definitely be felt and will be painful, but will not cause permanent damage if the person has a healthy constitution.

The effects are classified as follows:

Physiological effect	Thermal effect	Chemical effect
• Irritation of nerves • Sensation of pain • Muscular twitching • Muscular cramp "seizure" • Increased blood pressure • Cardiac fibrillations • Apnoea • Unconsciousness	• Current marks at the points of entry and exit • Tissue degradation • Coagulation • Burns	• Tissue decomposition

The occurrence of the effects listed depends on the level of the current. Chemical effects occur primarily after accidents involving direct currents. In the case of tissue decomposition, symptoms of poisoning often emerge several hours after the accident, even if the victim initially has no symptoms.

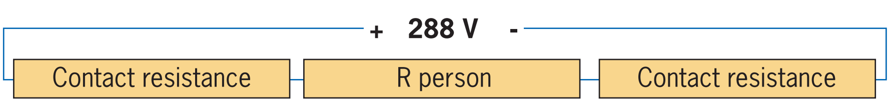
Bodily resistance

The level of the current flow from a specific voltage depends on the degree of resistance (Ohm's law). Protective measures are designed based on an assumed bodily resistance of 1000 Ω. Under the assumption that contact with live components is typically made with the hands (housing) and feet (ground) or the left hand and right hand, the 1000 Ω are calculated by adding the individual resistances of the extremities. The resistance of the skin is crucial here. The resistance of the inside of the body is negligibly small.

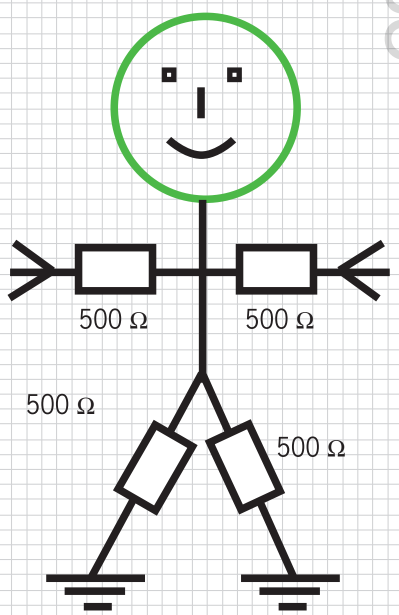
According to Ohm's law, a voltage of 288 V (high-voltage battery) produces a current flow of 288 mA at 1000 Ω (288 V/1000 Ω).

The level of the effective current flow is often significantly lower than a calculated value because the body connects with the contact resistances "in series" (gloves, surface paint, footwear, entire surface of hand does not touch component, etc.).

According to the laws of series connection, "poor" contact with the location of the fault reduces the contact voltage.



Effects may manifest themselves several hours after the accident. Therefore always seek medical attention after accidents involving electricity!



Arcing effect

Electrical currents can be dangerous even if they do not flow through the body. The energy stored in the high-voltage system is capable of generating electric arcs that can reach temperatures well in excess of 7200° F. (4,000° C.).

Electric arcs are generated by:

- poor connections, e.g. loose or oxidised contacts, damage caused by overtightening screws
- isolation faults
- the use of incorrect electric cables or connections (wrong size, shape, material)
- Moisture/Dirt (conductive dust)
- Foreign objects, falling metal components and small parts

If an individual is the cause of the electric arc or is standing in the immediate vicinity, the following effects can be expected.

Acoustic effects

- Trauma from acoustic shock

Thermal effects

- 1st to 4th degree burns
- Blindness or flash burn of the eyes from exposure to electric arcs
- Fire, melting of metal

Toxic effects

- Poisoning by gases or dust produced from ozone or decomposition products from the affected materials, for example

Electrodynamic forces

- Pressure waves
- Injuries from moving parts
- Spraying of liquid metal
- Bursting of housings

Secondary accidents

Subsequent defence or shock reactions can also cause secondary accidents:

- Injury caused by stumbling, falling or slipping
- Cutting, crushing, stab and graze injuries
- Injury caused by falling components

Actions in the event of an accident involving electricity

First aid

The main priority is to evacuate the person from the danger zone while ensuring one's own safety. When attempting to save the life of the victim of an accident caused by electrical currents, every minute counts and sometimes every second. Do not neglect your own personal safety under any circumstances.

- **Keep calm!**
- **Do not expose yourself to the risk of electric shock!**
- **Interrupt the electric circuit (engage a third party if necessary)**
  - **- Ignition off**
  - **- Unplug the service disconnector**
  - **- Isolate/Push the victim away from the power source using an electrically non-conductive object (e.g. piece of wood)**

Always evacuate the casualty from the danger zone and eliminate all immediate dangers (fire, active high-voltage components) to yourself and other people before initiating first aid measures.

- **Initiate first aid measures**
  - **- Call the emergency services or an emergency paramedic**
  - **- Notify the first aider or paramedic of the victim's location**
  - **- Move the victim to a normal position**
- **Check responsiveness of the victim**
- **Check breathing, pulse and circulation**
- **If the person if responsive, take appropriate actions to cool their burns**
- **Do not leave injured persons unattended until the emergency services arrive!**

Immediately after unplugging the service disconnector, treat the system as if it were still live. For your own safety, use a non-conductive object to push away the victim.

Assistance measures in the event of fire

- Do not breathe in any gases or smoke that may be generated
- Alert the fire department and inform them on arrival that the vehicle is a high-voltage vehicle
- Remove or cover any sources of ignition in the vicinity
- Always use CO_2 or ABC powder extinguishers to fight fires on electrical systems, alternatively use fire blankets
- Make sure that the fire has been extinguished properly to prevent smouldering fires from reigniting

Fire extinguishers

Always use CO_2, powder or foam extinguishers to fight fires on electrical systems. Due to the risk of suffocation, do not use CO_2 extinguishers on burning victims.

- Always keep fire extinguishers within easy reach
- Fire extinguishers must be filled and restored to a perfect functional condition after each use
- Fire extinguishers must be checked regularly (at least once every two years)
- Identify the location of the fire alarms and fire extinguishers
- Make sure that access to fire extinguishers and alarms is guaranteed at all times

Obligation to report accidents

In the event of an electrical accident, the emergency services must be contacted immediately because the fate of a patient depends on swift medical intervention from the emergency paramedic (advanced procedures).

The Dealer is obliged to install alarm systems and implement organizational measures with consideration for the operational conditions within the dealership to ensure that the rescue services can be called immediately and then directed to the scene of an accident.

The Dealer must ensure that the relevant telephone numbers are posted in a central, clearly visible location within the workshop so that the emergency response center can be contacted as quickly as possible.

The quality of the emergency call depends heavily on the content of the information provided.

The following list questions is generally advised:

WHERE did it happen?
WHAT happened?
HOW MANY casualties?
WHICH type of injuries/symptoms?
WAIT for queries!

Protective measures

Protective measures are designed to prevent the flow of dangerous currents through the body and protect system components from destruction. These may include measures that shut down the system completely in the event of a fault, design measures that prevent access to dangerous components and even the systematic use of harmless voltages (12-volt vehicle electrical system).

Fault types

The following types of fault occur in hybrid technology:

Short circuit

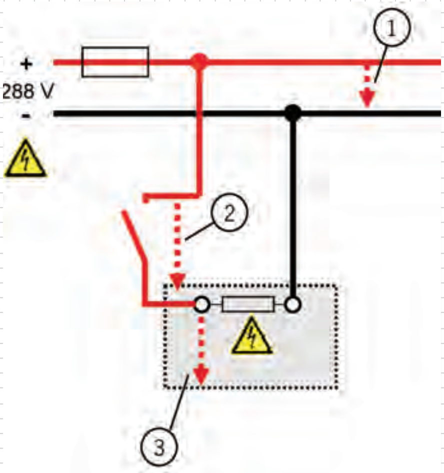
A conductive connection between two live active conductors with different voltages when no useful resistance is present in the faulty circuit. The overcurrent protective device (fuse) triggers.

Conductor fault

The conductor fault is a connection between live active conductors when a useful resistance is present in the faulty circuit. The overcurrent protective device does not trigger, but a malfunction occurs due to the continuous presence of the useful resistance (similar to a “sticking“ contactor).

Ground fault

An active conductor reaches the conductive housing of an object. When contact is made, contact voltages pass between the housing and the reference potential of the energy producer. The voltage levels depend on the contact resistances and the resistance of the actual object (series connection).



Fault types
1 Short circuit
2 Conductor fault
3 Ground fault

Contact resistances

Contact resistances are generated in several different ways. Usually they go unnoticed at first but grow over time and eventually affect the safety and function of the overall system.

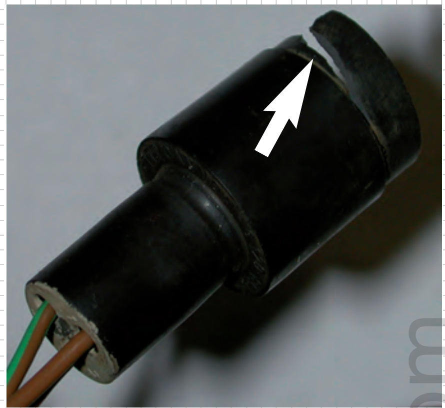
Contact resistances are caused by:

- Incorrectly seated or faulty connectors
- Corrosion resulting from moisture that enters the electrical connections
- Dirt and residues in electrical connections
- Dirty contact surfaces on ground connections or screw connections that form part of the equipotential bonding system
- Poor transitions from the line to the connector
- Cable cross sections too small

Contact resistances are connected in series with the electrical circuit and distort the voltage level on downstream components.

While contact resistances on a 12-volt system cause a voltage to decrease by only a few volts, the power transferred between high-voltage components is much higher. Contact resistances generate voltages that heat up contact surfaces considerably, the consequences of which can range from progressive damage to a risk of fire.

The isolation monitoring function of the battery manager detects any contact resistances generated around the equipotential bonding conductors, identifies them as system faults and restricts the functions of the hybrid system.



Tear in a rubber sleeve allows moisture to enter

Dirty contact surface on a ground connection

Identification of high-voltage components and high-voltage vehicles

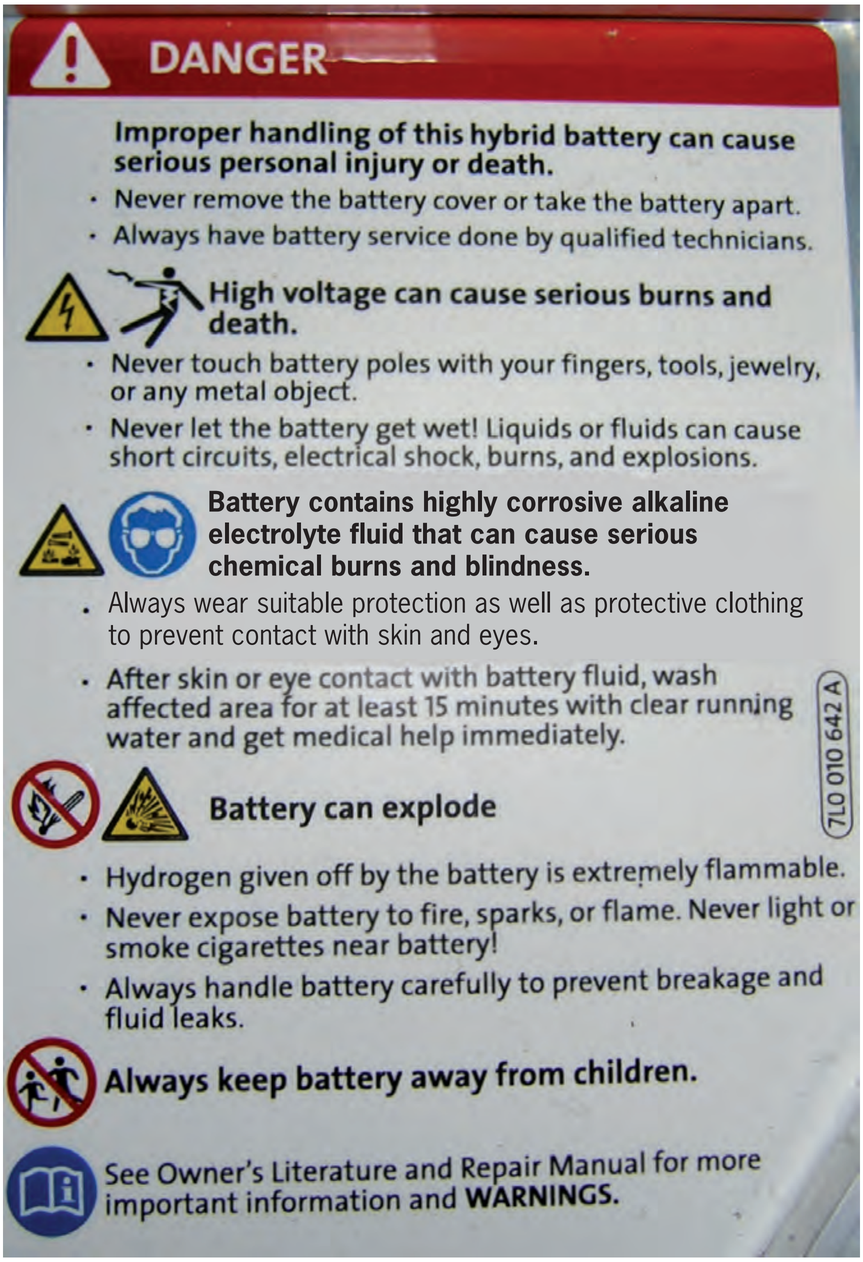
High-voltage components

Saftey warning labels that draw attention to potential dangers are applied to all high-voltage components.

All high-voltage connections are protected and orange in color, which makes them stand out clearly from other components in the vehicle.

Identification of HV components

Notice in engine compartment



Danger notices on the high-voltage battery

High-voltage vehicles

Warning signs must always be attached to hybrid vehicles residing in the workshop to draw the attention of third parties to potential dangers.

The high-voltage technician (HVT) is solely responsible for attaching warning signs to high-voltage vehicles correctly, disconnecting the high-voltage supply and starting the vehicle again after all the necessary work has been performed.

The five safety regulations

Five safety regulations must always be observed without exception before work is performed on the electrical system. Immediately after the high-voltage vehicle is driven into the workshop, the high-voltage technician must mark the vehicle accordingly (see warning sign on right). The name of the HVT responsible for marking the vehicle must appear on the sign.

1. Disconnection

The vehicle may **only** be disconnected by a high-voltage technician (HVT).
The following actions are required:

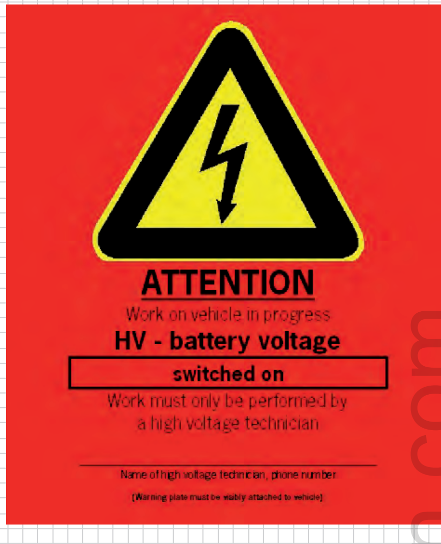
- Ignition off
- Remove service disconnector
- Remove the pilot line connector from the E-box
- Disconnect the high-voltage lines from the E-box

2. Securing against restart

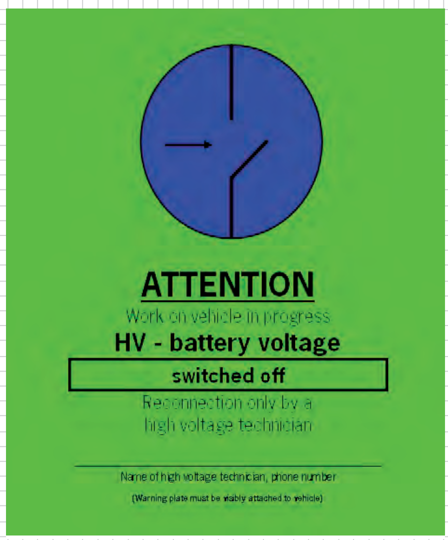
Ensure that no third parties are able to restart the high-voltage system.
The high-voltage technician (HVT) responsible must keep all components required to restart the system such as the:

- ignition key
- service disconnector and
- pilot line connectors

in a safe location to which only he has access.

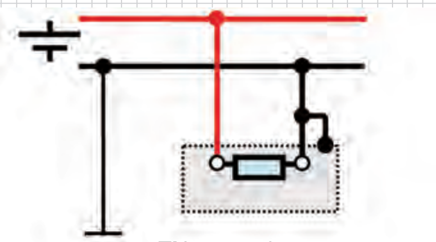


In a corresponding test report, the HVT must document that the vehicle has been disconnected and specify any tests performed to establish that the high-voltage supply is isolated correctly.
See workshop literature.

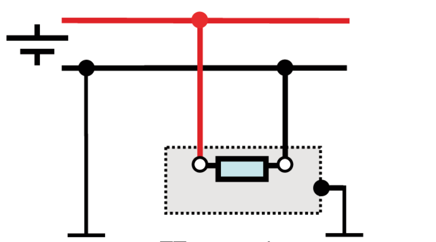


Only the first three regulations in the list apply to work performed on high-voltage vehicles.
Strict compliance with these regulations guarantees your own personal safety and the safety of others. See also "Competencies and responsibilities".

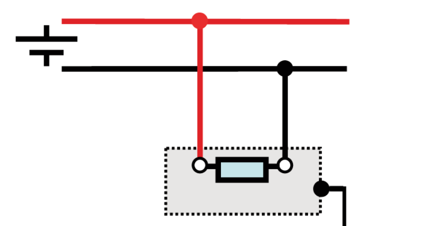
The simplified illustrations shown below represent the principles of the three different network types used in vehicle engineering.



TN network



TT network



IT network

3. Checking that the high-voltage system is disconnected correctly

The high-voltage system is tested metrologically to determine whether it is isolated from the voltage supply. The following measurements are made to check that the high-voltage system is isolated:

- Voltage detector check by applying a reference voltage
- E-box measured using a suitable measuring adapter after the high-voltage cables are disconnected
- High-voltage direct-current connections on the power electronics measured using the measuring adapter
- Reference voltage checked again

After de-energized state has been established, the vehicle must be marked to indicate this by the responsible HVT using the corresponding warning sign (see bottom of page 171). The name of the HVT must be shown on this sign. The red warning sign is removed.

4. Grounding and short-circuiting

Active conductors are also connected to the ground potential and the neutral conductor. On systems with a nominal voltage of less than 1,000 V, these measures are not required.

5. Covering or isolating adjacent live parts

Network types

Network types define the structures of the paths that transmit electrical energy. Energy providers or even the operator of an electrical system determine the network type, which may vary depending on the region. Depending on the selected network type, different measures that prevent dangerous currents from passing through the body are available or even required. While the most common network type used in private households nationwide is the TN system, an IT network is consistently used in hybrid vehicles.

Network types are identified by an alphabetic abbreviation.

The first letter defines the grounding state of the energy producer (transformer station or high-voltage battery)

T The transformer star point in the three-conductor network is connected to ground. In terms of vehicle technology, this represents a connection of the negative terminal on the 12 V battery to the vehicle ground.

I The energy producer is isolated from the ground or a shared reference potential. In hybrid technology, all high-voltage connections are completely isolated from the rest of the vehicle!

The second letter describes the grounding state of the energy consumer.

N Conductive housings on consumers are connected to the operating ground (producer) via a protective conductor or PEN conductor.

T Conductive housings on consumers are connected directly to the ground potential or a shared reference potential (vehicle body).

The first and second letters combine to form the three common network types: TN network, TT network and IT network.

Only IT networks are used in hybrid vehicles, which includes the Cayenne S Hybrid. Instead of a connection to ground, a connection to the vehicle body is established, which can be considered isolated from ground. The different versions do not take into consideration connections between a person and ground.

TN and TT system

TN network

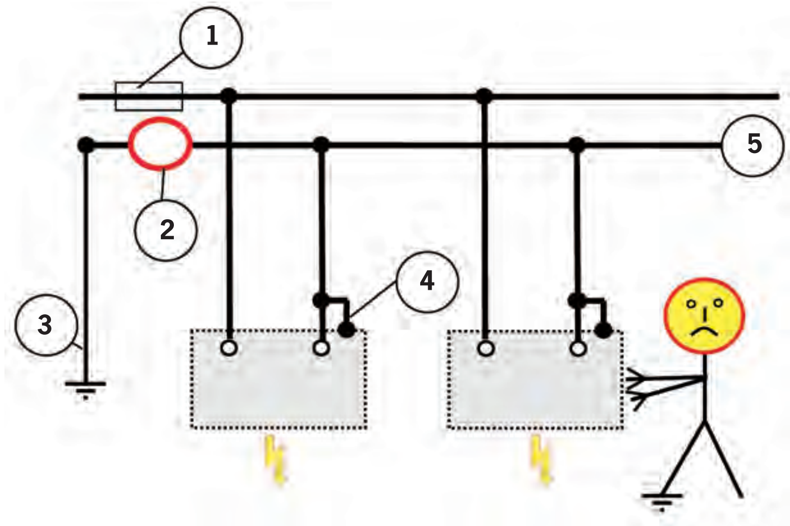
In the TN network, the star point of the energy producer is grounded.
The housings on the consumers are connected to the operating ground of the energy producer via the protective conductor and the PEN conductor (PEN = Protective Earth Neutral). There are two types of TN system:

- TN-C network
- TN-S network

TN-C network

In the TN-C system (C=combined), the neutral conductor simultaneously assumes the function of the protective conductor (see "Protection class 1") because the protective conductor is connected directly to the PEN conductor on the consumer and therefore connected to the operating ground as well. The disadvantage of this system comes at the moment during which the PEN conductor between the consumer and energy producer is interrupted. The connection between the protective and PEN conductors then makes available the full nominal voltage between **all** conductive housings and ground.

Non-functional equipment causes the system to adopt a de-energised state. If any part of the body makes contact with the housing, there is a risk of fatal injury. This type of network may therefore only be used for cable cross sections exceeding 10 mm^2. It is often used for the transmission path leading from the energy producer to the site connection box on the consumer. A sealed housing and larger cross sections ensure that the configuration is correct here.



TN-C system

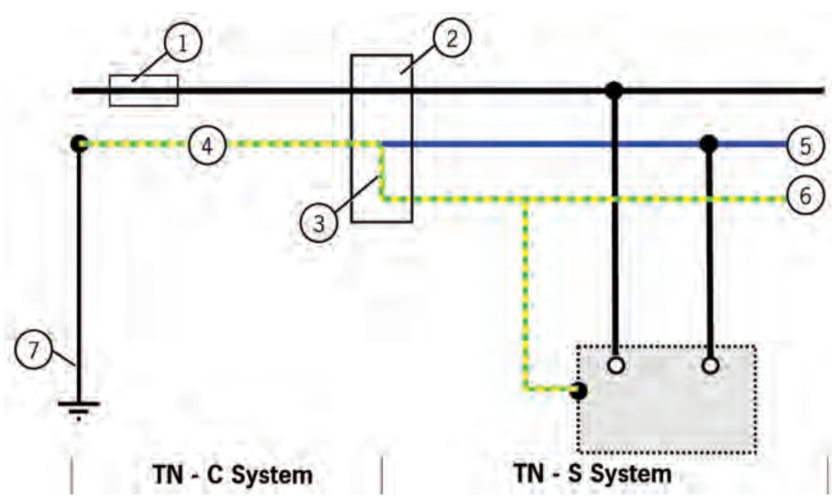
1 Fuse
2 Open circuit
3 Operating ground
4 Protective conductor
5 PEN and neutral conductor

TN-S network

In addition to the neutral conductor, the TN-S system (S=separated) incorporates a separate protective conductor (green-yellow) and is standard for structures at the consumer end. Equipment from protection class 1 is connected via the shared protective conductor. Only the TN-S system offers the possibility of using a fault current protection circuit (FI protection switch) as an additional protective measure.
The advantages of the two networks

- TN-C = fewer conductors
- TN-S = safe

are combined in the TN-C-S system. The longer transmission path between the energy producer and the consumer on the TN-C system is combined with the consumer installation on the TN-S system. In the site connection box (=transmission point), the PEN conductor is divided into neutral and protective conductors.



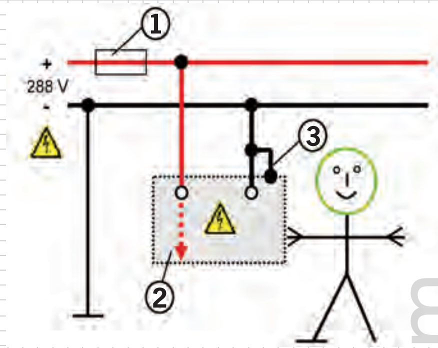
1 Fuse
2 Site connection box
3 Protective ground
4 PEN conductor
5 Neutral conductor
6 Protective conductor
7 Operating ground

A TN system does not mean that there is no ground in the consumer installation. Rather the "additional" system ground at the consumer end combined with the main equipotential bonding circuit is essential. In other words, the provision of a shared reference potential and connection with the grounding wire system and all other conductive parts of the building. The purpose of this configuration is to discharge potentials to ground and prevent impermissible contact voltages from developing when a fault occurs.

If the TN system were used in hybrid technology and a ground fault occurred, the connection between the housings and the reference potential (protective ground) would trigger the fuse. As a consequence, the high-voltage supply would fail during operation and this is one of the main reasons why this system is **not** used.

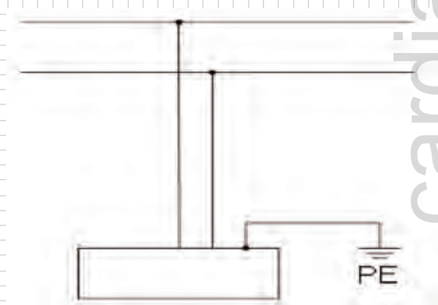
TT network

The TT network is used primarily in rural sectors and only very rarely. Unlike the TN network, conductive housings are **not** connected with neutral conductors (no protective ground), but instead are connected to the ground potential. The ground contact resistances must be very low so that the fuse can trigger quickly enough if a fault occurs.

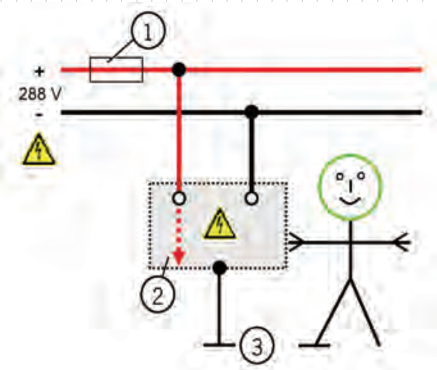


TN system

1 Fuse
2 Ground fault
3 Protective



TT system



IT system hybrid

1 Fuse
2 Ground fault
3 Body

IT network

In the IT network, the energy producer (high-voltage battery) is not connected to the reference potential. Appropriate measures have been taken to isolate both terminals on the high-voltage battery from the vehicle body (reference potential). Isolation must be guaranteed through the introduction of suitable design features and continuous monitoring. If the electrical system is spread over a large area, the capacitances in the lines ensure that the longer the transmission paths, the smaller the leakage resistance. As a result, larger systems cannot be integrated as an IT network.

The major advantage of an IT system is the isolation of the energy producer from the reference potential.

In a similar way to protective separation, current does not flow between the housing and the body of the vehicle in the event of a fault (ground fault). Furthermore, the fuse does not shut down the system in the same way as the TN system because a system shutdown is not necessary. The high-voltage system remains operative (1 fault system) and the hybrid vehicle can therefore visit the workshop without posing a danger.

On the Cayenne S Hybrid, the battery manager is responsible for monitoring the leakage resistance. It measures the leakage resistance by comparing the current and voltage values in the overall system. If the values are different, the battery manager assumes that an insulation fault is generating a current flow.

A detected insulation fault is indicated on the instrument cluster by a yellow warning lamp.

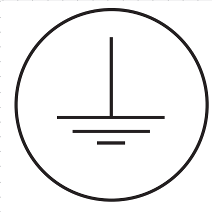
The HV system is switched off if a second insulation fault is detected. The warning indicator is now shown in red. This means that the vehicle can now be operated only with the combustion engine, and renewed starting is no longer possible.

Classification of devices into protection classes

All equipment connected to supply networks provided by power companies belong to one of three protection classes.

Protection class 1 - Protective grounding

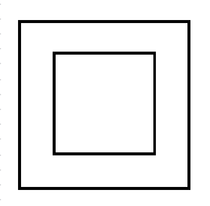
This protection type is used for devices with housings manufactured from electrically conductive material. The housing is connected to the protective conductor (PE - protective earth) on the electrical system, which results in a protective ground and guarantees an equal potential between the housing and the protective conductor. Working voltages are discharged to ground or a shared reference potential via the protective conductor. The ground symbol is used to identify these devices. Typical protection class 1 devices include household appliances such as cookers and toasters, etc.



Protective conductor connection
Protection class 1

Protection class 2 - Total insulation

Devices from protection class 2 have basic insulation and additional insulation. If there is contact between an active conductor and the inner sheath, no voltage is present at the housing. Most devices from protection class 2 have plastic housings and no protective conductor connection. The device identification symbol indicates a double housing.

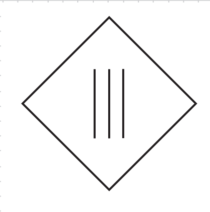


Total insulation
Protection class 2

Protection class 3 - Safety extra-low voltage

SELV - Safety extra-low voltage

The safety extra-low voltage is solely a protective measure. The operating voltage of the devices is below the minimum contact voltage of 50 V AC or 120 V DC permitted for people. These include children's toys and 12-volt halogen lamps, for example. The devices must be fitted with a protective isolator. In order for the isolator to work effectively, there must be no connections to a reference potential. The 12-volt vehicle electrical system does not fulfil this requirement because the 12 V negative terminal is connected to the body. Battery-operated devices such as pocket lamps or mobile phones fulfil this requirement without the need for further technical modifications.



Safety extra-low voltage
Protection class 3

FELV - Functional extra-low voltage

The functional extra-low voltage (FELV) is not an independent protective measure. In the same way as the safety extra-low voltage, the operating voltage is less than the minimum permitted values but is solely functional. Devices with a functional extra-low voltage do not fulfil other requirements for dielectric strength, for example. Examples include different control systems and even the 12-volt electrical system on motor vehicles.

The currents that flow in the 12-volt vehicle electrical system are immensely high, but cannot flow through a person due to the comparably high resistance of the human body. In the case of direct, full contact (hand-hand) with the 12-volt battery terminals, the maximum current is a mere 12 mA (12 V/1,000 Ω). The secondary effects (burns from electric arcing, mental shock) represent a danger, however.

Classification of protective measures

Protective measures are divided into three areas. This multi-level concept illustrates the takeover function adopted by the most important protective measures when a protective measure fails.

Basic protection –>	Fault protection –>	Additional protection
Protection from direct contact. e.g. insulation of cables	Protection against indirect contact. e.g. protective separation	Effective if basic protection and fault protection fail. e.g. equipotential bonding

Basic protection

- Protection from direct contact

This category includes the basic insulation of active high-voltage components in the vehicle. This protection type classifies the degree to which equipment is protected from contact, foreign bodies and water. In this case basic protection is provided. The standardised classification of protection types is specified in ISO 20653 (International Standards Organization) and DIN 40050/EN 60529. The IP code includes the degrees of protection and defines the protection type.

Protection types according to ISO 20653

IP X X X X

1. 1st digit, degree of protection for foreign bodies and shock-hazard protection

X Not allocated

0 Not protected

1 Protected against ingress of objects > 50 mm (back of hand)

2 Protected against objects > 12.5 mm (fingers)

3 Protected against objects > 2.5 mm (tools)

4 Protected against objects > 1 mm (wire)

5K Dust protection

6K Dust-proof

2. 2nd digit for water protection

X Not allocated

0 Not protected

1 Protected against vertical drip water

2 Protected against drip water (max. deviation 15° from vertical)

3 Protected against spray water (from one direction)

4 Protected against spray water (from any direction)

4K Protected against spray water (from any direction, pressurised)

5 Protected against spray water (from any direction)

6 Protected against strong water jets (any direction, pressurised)

6K Protected against strong water jets (any direction, pressurised)

7 Protected against temporary immersion

8 Protected against permanent immersion (pressure may be specified)

9K Protected against high-pressure cleaning

3. 3rd digit, additional shock-hazard protection (optional)

A Protected against access with back of hand (> 50 mm)

B Protected against access with fingers (> 12.5 mm)

C Protected against access with tools (> 2.5 mm)

D Protected against access with wires (> 1 mm)

4. 4th digit, supplementary (optional)

M Water protection applies for moving parts (e.g. rotor)

S Water protection applies for stationary parts

H High-voltage equipment (only in DIN/EN)

W Tested for specific weather conditions (only in DIN/EN)

Two-digit protection types originating exclusively from the electrical engineering sector (such as IP 54) have been extended especially for road vehicles (high-voltage technology). These extensions affect single-digit degrees of protection which have been replaced by two digits ending with a K.
A third and fourth digit were also added to take into account workshop requirements and the testing of moving parts. Standardisation according to DIN or EN deviates from the international standard in certain cases.
In high-voltage technology, the different variations are heavily restricted by the minimum requirements for shock-hazard protection.

IP X X X X

1. 1st digit

X Not allocated
5K Dust protection
6K Dust-proof

2. 2nd digit for water protection

X Not allocated
4 Protected against spray water (from any direction)
6K Protected against strong water jets
7 Protected against temporary immersion
9K Protected against high-pressure cleaning

3. 3rd digit, shock-hazard protection

A Protected against access with back of hand
B Protected against access with fingers
C Protected against access with tools
D Protected against access with wires

4. 4th digit, supplementary

M Water protection applies for moving parts
S Water protection applies for stationary parts

Examples for shock-hazard protection

IPXXB

Equipment is protected against access with fingers.

IPXXD

Equipment is protected against access with a wire (> 1 mm). Contact/Water protection according to DIN is not specified.

The classification of high-voltage components used by Porsche

High-voltage component	Protection type	Meaning
High-voltage battery with E-box (without ventilation system!)	IP5K4	Protection against dust/ spray water from any direction
Electric machine with electrical connections	IP6K7	Dust-proof/Protected against temporary immersion
Power electronics	IP6K7 & IPX9K	Dust-proof/Protected against temporary immersion and high-pressure cleaning
All high-voltage connections	IP6K9K	Protected against high-pressure cleaning

At Porsche, degree of protection IPXXB is also valid for contact surfaces on disconnected plugs. Degree of protection IPXXD is the minimum protection type for all operational high-voltage components.

Fault protection

- Protection against indirect contact

Indirect contact exists if faults (e.g. ground fault) on system components that are usually free of voltage connect voltage potentials to other components.

Protective measures are divided into two groups with and without protective conductors.

Measures without protective conductors

Total insulation

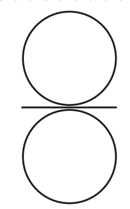
All devices from protection class 2 fall into this category (see "Classification of devices into protection classes“).

Safety or functional extra-low voltage (SELV/FELV)

See "Classification of devices into protection classes".

Protective separation

An isolating transformer galvanically isolates the primary end connected to the reference potential from the secondary end. In the event of a fault, current cannot flow towards the reference potential. Isolating transformers are marked with a corresponding symbol. Refer to the chapter on protective separation.



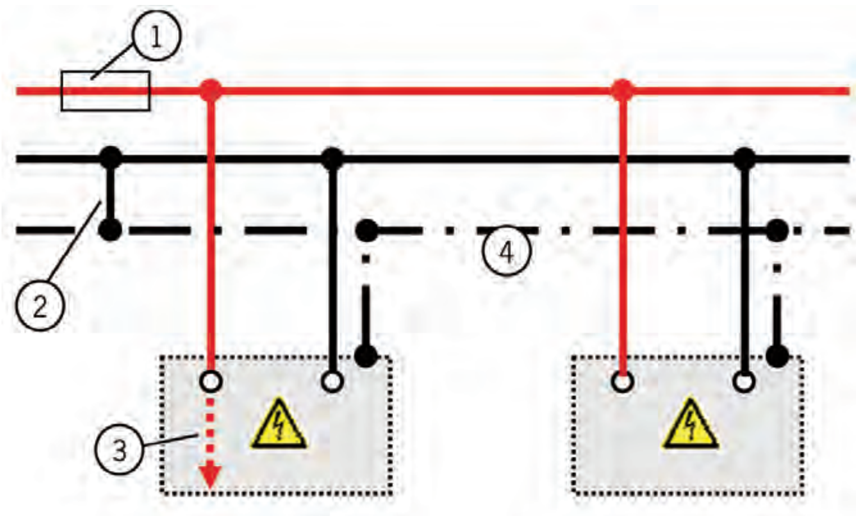
Protective separation

Measures with protective conductors

The protective conductor (PE - protective earth) connects conductive, touchable inactive system components to one another and may only be used for this purpose. The green-yellow color is permitted exclusively for protective conductors.

Protective ground

The protective conductors on the system are connected to the PEN/neutral conductors. In the event of a ground fault, the fault current generated is so large that the high-current protection mechanisms (fuses) can trigger within 0.2 s. The fuses integrated in the protective measures are designed to protect the line. The ground fault then becomes a short circuit!



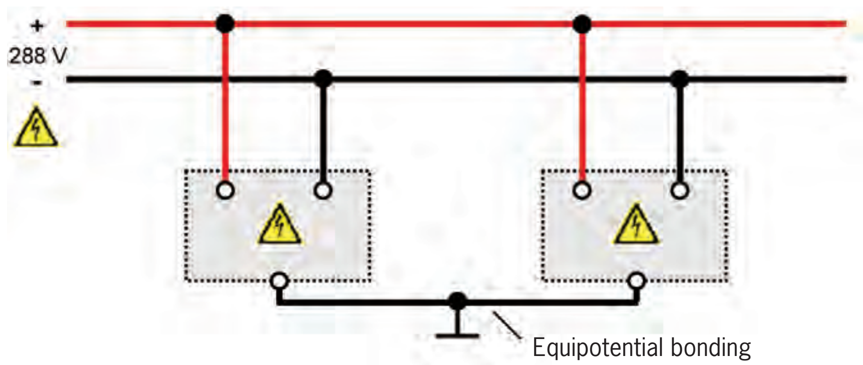
1 Fuse
2 Protective ground
3 Ground fault
4 PE conductor

Grounding wire system (IT network with isolation monitoring)

The grounding wire system (not to be confused with the protective conductor system) consists of the protective measures used in hybrid vehicles.

The IT system (see Network types) is combined with a function that monitors the isolation of the producer from the reference potential (body).

All elements on the high-voltage system are connected with one another (equipotential bonding). Generated contact voltages are diverted to the vehicle body.



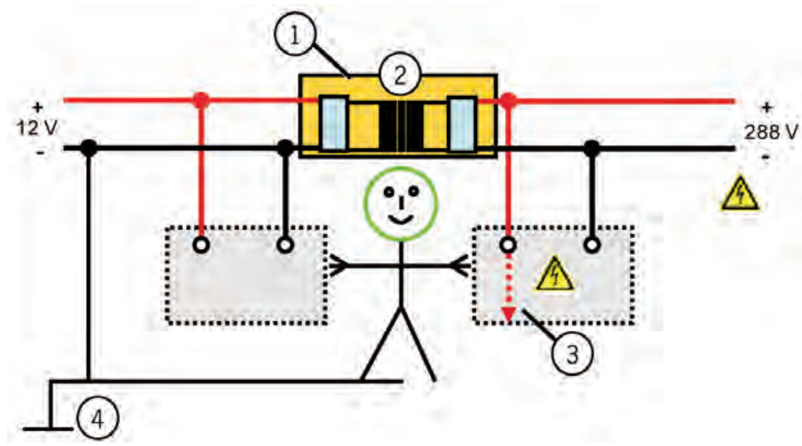
For other versions, see IT network and equipotential bonding.

The area 2 fault protection measures become ineffective if another fault occurs in addition to the first fault.

Protective separation

Protective separation prevents contact resistances from occurring between different energized areas or current circuits and is usually achieved through an isolating transformer (galvanic isolation) that disconnects the active parts (i.e. live under normal conditions) from the reference potential completely. Reference potential refers to the vehicle body here. A technician is also "connected" to the body when working normally on the vehicle (leaning, supporting, etc.). The additional connection to ground can be ignored because motor vehicles are already regarded as being isolated.

The protective isolator is integrated in the DC/DC converter between the 288-volt and the 12-volt areas.



1 DC/DC converter in the power electronics
2 Galvanic isolation
3 Ground fault at high-voltage end
4 Connection to body

If a ground fault occurs on a high-voltage component, impermissible contact voltages are not generated between a housing and the reference potential or the remaining 12-volt potential. Without this protective isolator, it would not be possible to isolate the high-voltage area from the reference potential.

Additional protection

- If the basic protection and fault protection fail

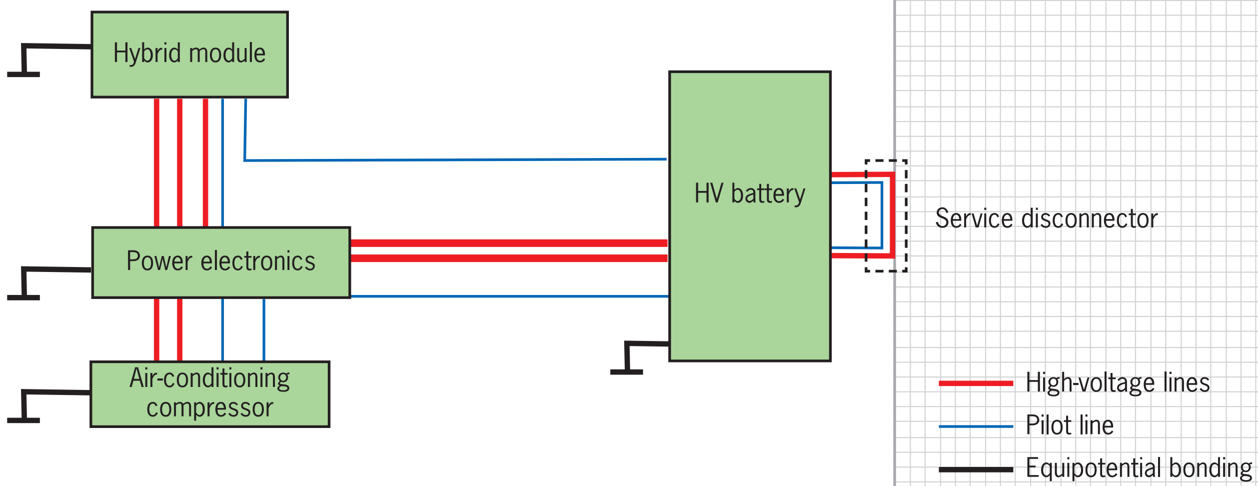
Additional protection measures prevent dangerous contact voltages from occurring if the measures for area 1 **and** 2 fail.

Residual-current device protection

The residual-current circuit breaker measures the sum of the currents flowing in both directions within the system. If a current flows to ground through a person, for example, the two currents are no longer the same. If this differential current exceeds the trigger current (e.g. 30 mA), the residual-current circuit breaker shuts down the system at all terminals within 0.2 s.

Pilot line

The pilot line is a ring line that loops through all high-voltage components.
Open circuits in the line are identified by the battery management system (BMS) and the high-voltage system is actively discharged as a consequence.



Active discharge

Controlled by the battery management system, active discharging reduces residual voltages in the high-voltage system and is performed every time the system is switched off or an open circuit is detected in the pilot line.

Passive discharge

High voltage-components discharge without intervention from the battery management system so that residual voltages in the capacitances are discharged rapidly after the power electronics are removed, for example.

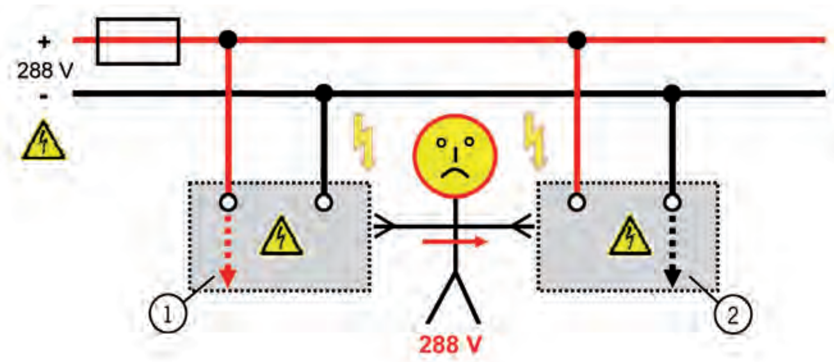
Equipotential bonding

Equipotential bonding is a connection between all touchable, conductive and inactive parts (i.e. live under normal conditions) of an electrical system. All housings on the high-voltage components are connected to the vehicle body.

The main task of equipotential bonding is to prevent impermissible contact voltages caused by induction or faults within the system and the failure of basic and fault protection measures, and divert these voltages to the shared potential (vehicle body).

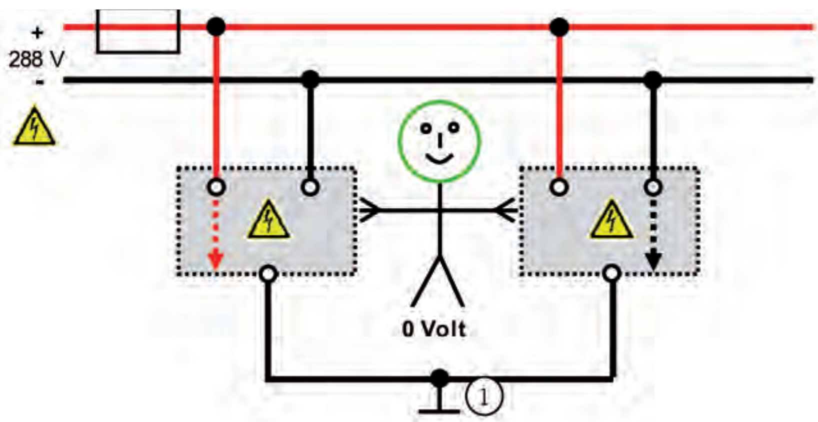
In Porsche hybrid vehicles, equipotential bonding safely discharges contact voltages in conjunction with the relevant IT network. Combined with other measures, this system fulfils the requirements for intrinsically safe high-voltage vehicles.

In the following example, which does not include equipotential bonding, a second ground fault occurs in the IT network and connects the housing with the negative terminal on the battery. 288 volts are present between the housings. The fuse does not trigger.



1 First ground fault
2 Second ground fault

The equipotential bonding in the illustration below short circuits these voltages and discharges them via the body.



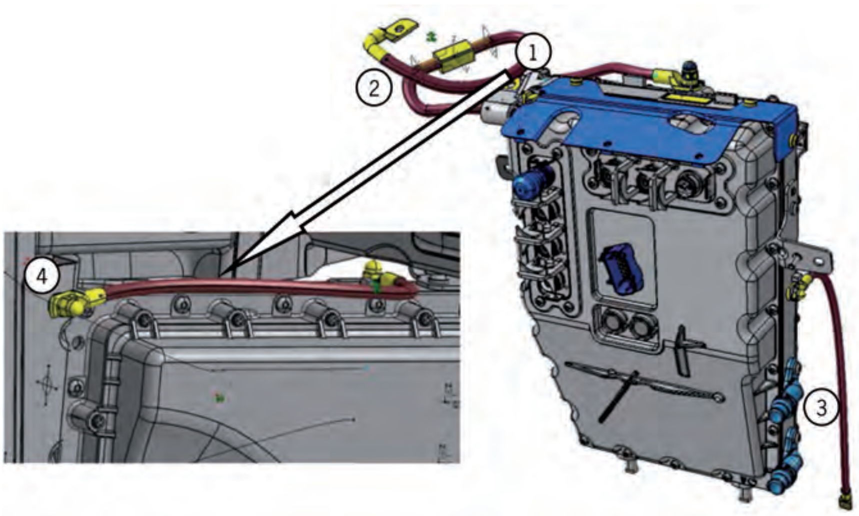
1 Equipotential bonding to body

A connection established between the two terminals on the high-voltage battery causes the fuse to trigger. Dangerous contact voltages do not occur, even momentarily, if the contact resistances involved in equipotential bonding are small enough in relation to the resistance of the body.

Implementation
Equipotential bonding is realized by way of a conductor with black insulation. This connects the components and the vehicle body. The main elements of the equipotential bonding system are the housings from the following components:

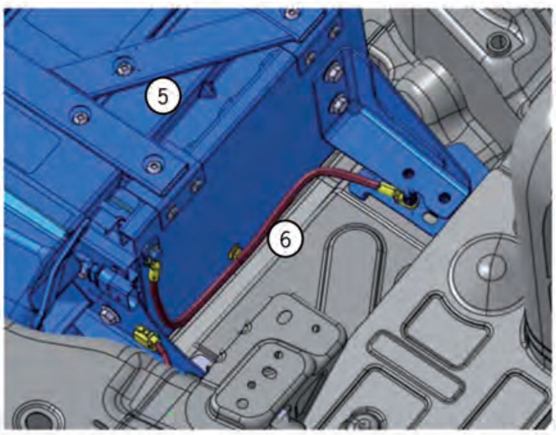
- Power electronics
- High-voltage battery
- Electric machine
- High-voltage air-conditioning compressor

The ground straps are secured on both sides with grounding bolts. The following illustrations show the configuration of the power electronics and the high-voltage battery.



Power electronics

1 12 V battery ground strap, negative
2 12 V battery, positive
3 Equipotential bonding
4 Connection between 12 V battery negative and body



High-voltage battery

5 Battery housing
6 Equipotential bonding

The effectiveness of equipotential bonding depends directly on the quality of the configuration. All contact surfaces must be clean and free of grease. The battery manager evaluates the contact resistances as isolation faults! See Workshop Manual.

Safety and functional extra-low voltage (SELV/FELV)

Even the safety and functional extra-low voltages offer effective additional protection. Please refer to "Classification of devices into protection classes" for details on the SELV and FELV.

Porsche high-voltage safety concept

Definition of intrinsic safety

In order to fulfil the requirements in the workshop on a day-to-day basis, different requirements were formulated for the high-voltage technology installed in hybrid vehicles, resulting in the definition of “Intrinsically safe high-voltage systems in motor vehicles“:

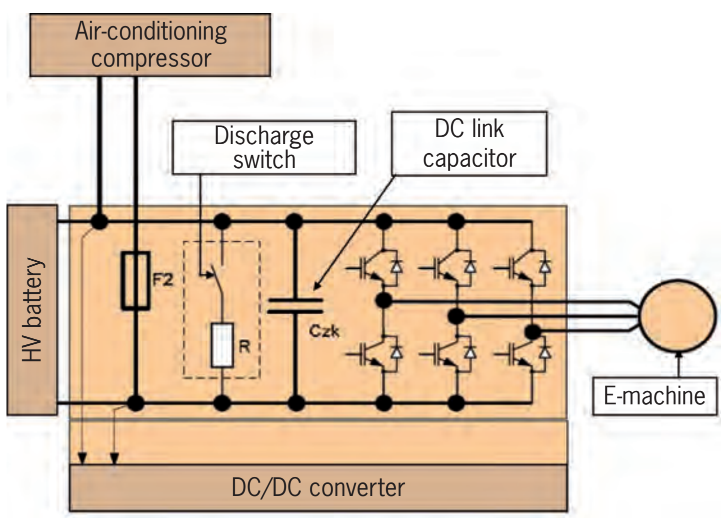
The technical measures implemented in "intrinsically safe high-voltage systems in motor vehicles" ensure that personnel cannot come into contact with high voltages or high-voltage electric arcs at any time.

This was achieved by implementing a combination of basic, fault and additional protection measures.

Intrinsic safety measures

Active discharge

Active discharge reduces the voltages levels at the connections on all high-voltage components to a direct current level below 60 volts within 5 seconds. The voltage is actively discharged through the components every time the high-voltage system is switched off. The battery manager (BMS) initiates the active discharge process. Active discharging ensures that the so-called DC link capacitor is discharged. For this purpose, the two potentials are short circuited via a switch and a resistor. The HV battery was already disconnected before this (contactors in E-Box de-energized/open).



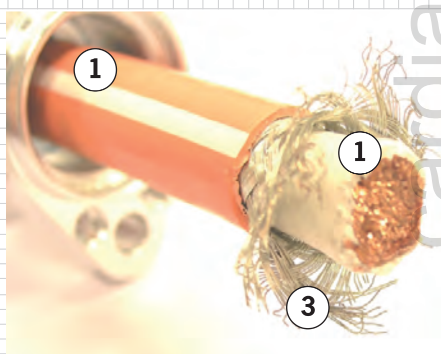
Passive discharge

Passive discharge refers to the autonomous discharge of high-voltage components. Passive discharge is not controlled. When the high-voltage power supply is off, the voltage at the connections on the high-voltage components decreases to less than 60 volts within 2 minutes.

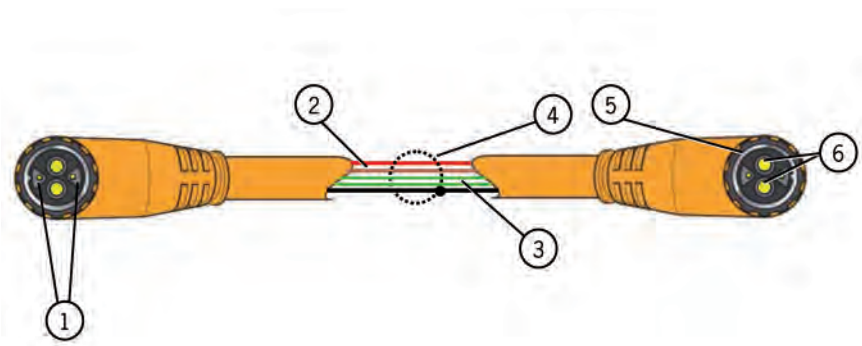
High-voltage wiring

All high-voltage connections on the Porsche hybrid drive are orange in color, which makes them stand out clearly from standard vehicle wiring. In addition to the basic insulation, all cables are provided with sheathing that additionally protects the HV cables against mechanical or thermal damage.

1 Insulation
2 Sheath (aramid/kevlar fabric)
3 Shield

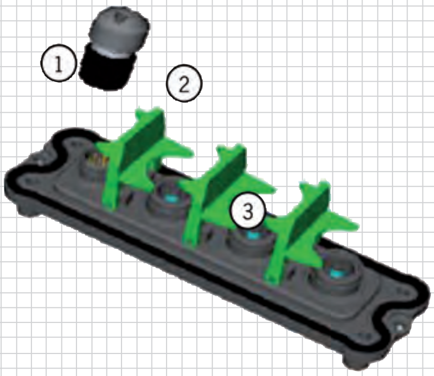


Many different types of high-voltage cable are used. The three connections from the power electronics to the electric machine and the connection from the high-voltage battery to the power electronics all contain a single wire. Apart from the internal conductor, a shield located between the inner and outer insulation provides immunity against electromagnetic interference and is connected to the vehicle ground. In the event of damage to the insulation (insulation fault), the shield can also perform the function of safely discharging the potential present to vehicle ground.

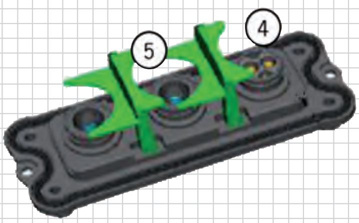


1 Pilot line contacts
2 High-voltage conductor
3 Pilot line
4 Shield
5 Ring contact shield
6 High-voltage contacts

The power electronics and the air-conditioning compressor are connected by a four-wire cable that contains the supply and return cables of the pilot line as well as the two high-voltage conductors (288 V DC).



Connections to electric machine
1 Pilot line connector
2 Locking mechanisms
3 To electric machine

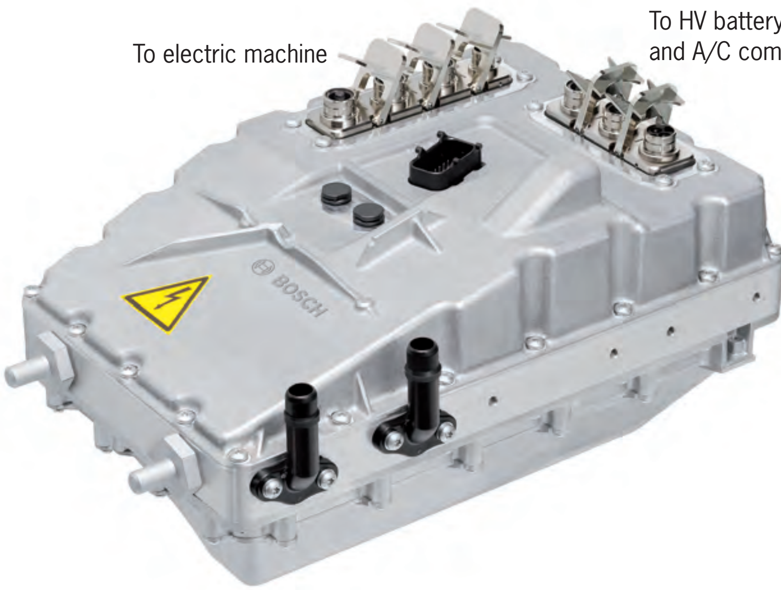


4 Connection to air-conditioning compressor
5 Connections to high-voltage battery

Amphenol high-current connection system

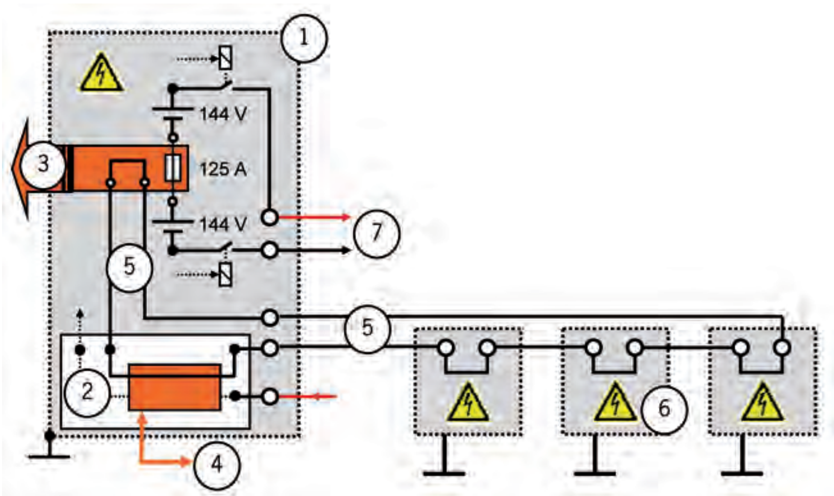
The high-current connection system allows the interruption of the pilot line before or during removal of the high-voltage lines. This is achieved via the pilot line connectors on the high-voltage battery connections as well as the high-voltage connections on the power electronics that lead to the electric machine. When inserted, the pilot line connector blocks the locking mechanisms for the high-voltage lines.

Pilot line connectors are not incorporated into the connecting unit on the power electronics, to which the high-voltage connections from the high-voltage battery and air-conditioning compressor are connected. Instead, the pilot line is integrated in the line to the air-conditioning compressor and must be removed first, similar to the pilot line connector.



Pilot line

The pilot line is a ring line that ensures all high-voltage components are connected correctly and indicates to the battery manager that the connections are intact. As shown in the diagram below, the pilot line runs alongside all the high-voltage components (6) to the E-box (1) through the battery manager (2 - BMS) and the service disconnector (3).



1 E-box
2 Battery manager (BMS)
3 Service disconnector
4 Crash signal
5 Pilot line
6 High-voltage components
7 High-voltage connection to power electronics

The pilot line is interrupted in either of the following cases:

- The pilot line connector or the line to the air-conditioning compressor has been removed and a high-voltage connector (orange line) is disconnected
- Detaching the service disconnector

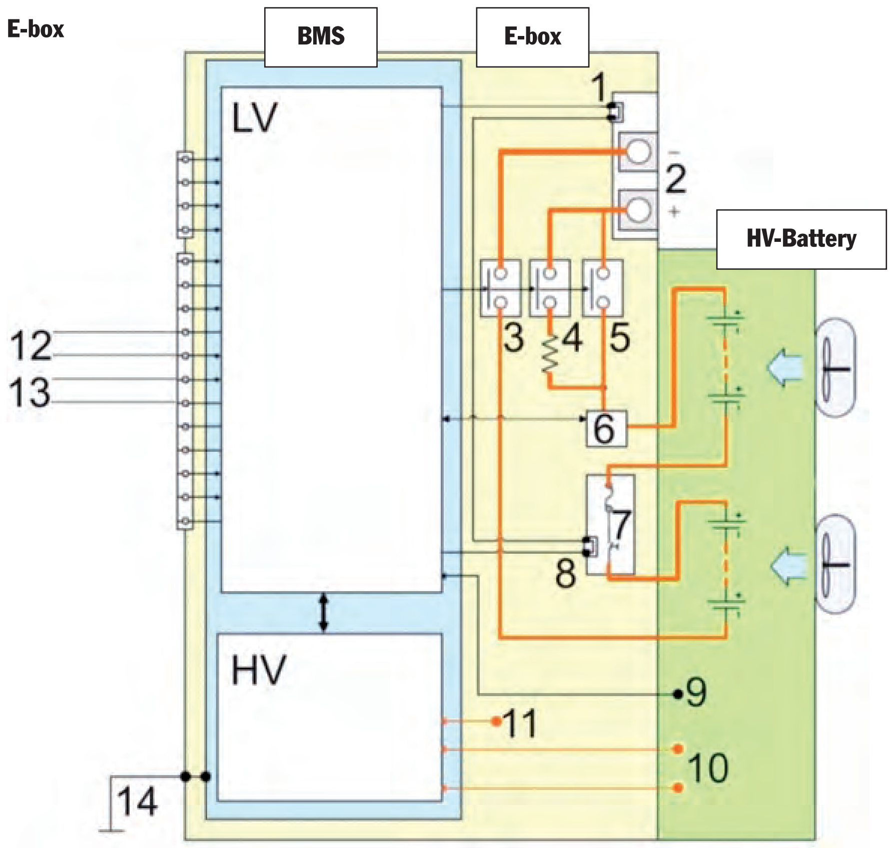
An open circuit in the pilot line:

- shuts down the hybrid system immediately
- actively discharges the high-voltage components

EMC measures

Suitable measures must be introduced to minimise disturbance variables that occur during the transmission of electrical energy. EMC measures (electromagnetic compatibility) reduce the emission of electromagnetic waves passively, in the same way as the shields in all high-voltage lines, and the Porsche hybrid system uses active filters to reduce the remaining interferences from the high-voltage system to a minimum. EMC measures are mostly located in the power electronics because the rapid switching of high loads generates current and voltage peaks that may be transmitted to other structural components.

1 Pilot line connector
2 HV connections to power electronics
3 Contactor for HV negative
4 Contactor for HV positive, pre-charging/diagnosis
5 Contactor for HV positive
6 HV current sensor
7 Service disconnector
8 Pilot line contact on service disconnector
9 Temperature sensors in HV battery
10 HV module current sensors and sensors for measuring isolation in HV battery
11 HV sensor in E-box
12 Pilot line input/output
13 Airbag signal input/output
14 Equipotential bonding to vehicle body
LV Battery manager (BMS), low-voltage area
HV Battery manager (BMS), high-voltage area



1 Service disconnector
2 Pilot line connector
3 HV connections

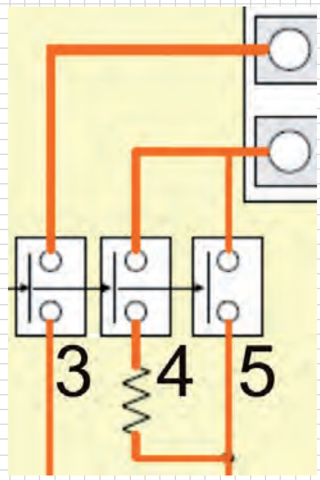
The connection unit on the high-voltage battery is called an E-box. As shown in the illustration above, the E-box contains the battery manager (BMS) and forms the connecting link to the high-voltage battery.

Battery manager

The battery manager is located to one side under the service disconnector and high-voltage connections, and communicates with the other vehicle components via the CAN Hybrid bus and CAN Drive bus. The main task of the battery manager is to monitor the battery charge state and switch off the high-voltage system in the event of a fault. The battery manager performs the following safety-relevant tasks:

- Monitoring of leakage resistance
- Controlling active charging of the high-voltage system after a fault or intentional shutdown
- Monitoring and influencing variables such as the charge and discharge current, battery temperature, module voltages and charge state

The battery manager monitors the leakage resistance of the high-voltage components during the hybrid system initialisation phase and during operation. Fault currents can be identified by comparing the data of the current sensors for the high-voltage battery and power electronics, and monitoring the state of the hybrid module. Other sensor values monitored by the battery manager include values from the voltage, current and temperature sensors in the high-voltage battery and the E-box as well as other information that the battery manager can access via the vehicle network (CAN-BUS). Depending on the importance of the fault, the battery manager intervenes in the hybrid system accordingly and displays the information for the benefit of the driver. In the event of a fault, the battery manager can be activated separately. When the high-voltage battery is replaced, the battery manager must be replaced as well.



Contactors

The contactors (3,4,5) installed in the E-box establish the connection between the high-voltage battery and the high-voltage accumulator. The battery manager activates and therefore supplies the current voltage of 288 volts to the power electronics. If the system is started with the ignition key (terminal 50) contactors 3 and 4 are closed first of all. A low voltage is initially supplied to the power electronics via the ballast resistor, which is connected in series. The resistor reduces the charge/discharge current. The capacitors in the power electronics are pre-charged during this phase. At the same time, the battery manager tests the high-voltage system using reduced values. If the hybrid manager establishes that the system is functioning correctly, contactor 5 is closed. The full high-voltage current (288 V DC) is then supplied to the power electronics.

!

The battery management system checks the status of the contactors. If the high-voltage system shuts down more than five times under load, the E-box must be replaced together with the high-voltage battery. The status can be retrieved via the PIWIS Tester.

Service disconnector

A high-voltage fuse connected in series with the battery cells and a contact for the pilot line are located inside the service disconnector in addition to the high-voltage contacts. Unplugging the service disconnector therefore has two main consequences:

locked

pilot line interrupted

unlocked

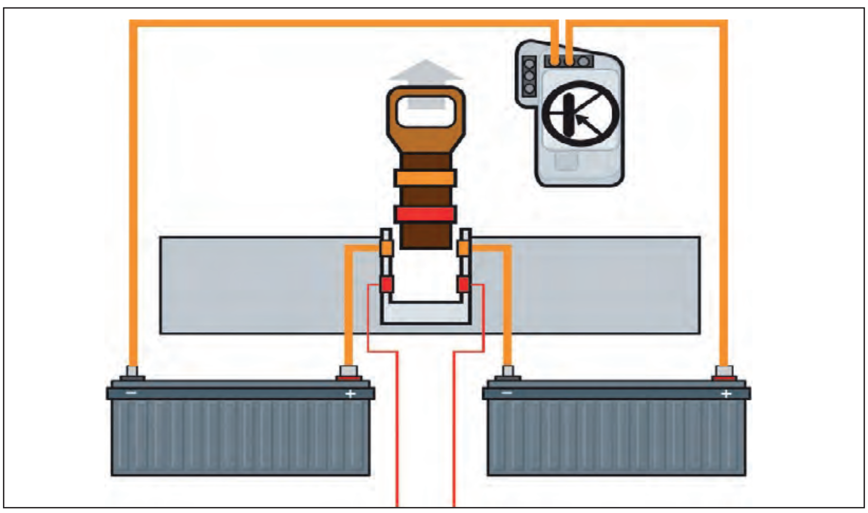
removed

Interrupting the pilot line

Moving the service disconnector to the right interrupts the pilot line contacts. The battery manager no longer activates the contactors as a consequence. The lines to the power electronics are interrupted. The vehicle can no longer be driven. Active discharging drains the residual voltage at the connections on the power electronics.

Separating the series connection

The two 144-volt battery strands are separated. The battery voltage present at the battery terminals decreases from 288 V DC to 144 V DC. At the end of the discharge process, no voltage is present in the power electronics.



Pilot line

Overcurrent protective devices

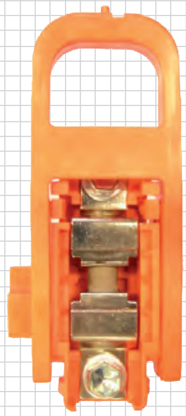
The hybrid system on the Porsche Cayenne S Hybrid is fitted with two high-voltage fuse elements that prevent overloading or overheating of the high-voltage lines and high-voltage components as a fire protection measure in the event of overcurrent, e.g. short circuits caused by an accident. The inserts are located:

- in the service disconnector
- in the power electronics

The charge/discharge current from the high-voltage battery flows directly through the fuse in the service disconnector. In other words, this fuse would trip in the event of a short circuit in the DC HV system (HV battery, E-box, HV lines to power electronics). When the fuse triggers, the battery voltage decreases to 144 volts. Passive discharging then occurs. The vehicle can no longer be driven. Only the 12-volt battery supplies power to the vehicle electrical system.

A fuse in the power electronics protects the line to the air-conditioning compressor and the air-conditioning compressor itself. The fuse cannot trigger during normal driving mode because the power consumption of all components is monitored by current sensors and the battery management system has control. If the fuse triggers, power is no longer supplied to the air-conditioning compressor. The battery manager prevents the high-voltage battery from overheating due to a lack of cooled air from an "unconditioned" cabin.

The second fuse located in the power electronics can trip in the event of faults in the integrated DC/DC converter. After the fuse has tripped, the 12 V vehicle electrical system can no longer be supplied with power, but the HV system is not affected and can continue operating. After this fuse has tripped, the vehicle remains fully functional until the 12 V vehicle electrical system voltage falls to such an extent that the low-voltage loads can no longer be supplied with sufficient power.



If the fuse is faulty, the service disconnector or power electronics must be replaced.

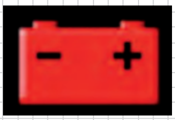
Hybrid-specific displays

Two displays on the instrument cluster provide the driver with information on the state of the hybrid system and any malfunctions that have occurred. Additional information also appears at the bottom of the display.

Warning and information messages

The yellow high-voltage battery symbol appears when hybrid system functions are restricted. Information also appears on the multi-function display.

The yellow hybrid warning lamp informs the driver that a fault has been detected in the hybrid system. The vehicle remains ready to drive but the hybrid system operates to a limited extent only depending on the fault. The driver must visit the workshop to have the fault rectified.



Fault messages

A red battery symbol indicates that a fault has been detected in the 12-volt vehicle electrical system (DC/DC converter).

If the hybrid system is deactivated, the vehicle can only be driven with the combustion engine at reduced power. Restarting the combustion engine is not possible. The vehicle must be parked in a safe place or driven immediately to the nearest workshop.

See also Driver's Manual.

Measurements on the high-voltage system

Measurements in the high-voltage area must always be taken using measuring adapters, that have connectors compatible with the Porsche high-voltage system. In addition to the VAS 6558 measuring adapters, an approved voltage detector that meets the requirements of at least overvoltage category CAT III is also required for voltage measurements, as well as a special insulation resistance meter.


Voltage detector

Insulation resistance meter

Three different measuring adapters are available for taking different measurements.

Adapter 1 (VAS 6558/1-1)

The DC voltage is measured at the connections on the power electronics or the high-voltage battery to establish whether an electric charge is present after the service disconnector is unplugged and before work is started on the hybrid components. The functional performance of the voltage detector must be tested with a reference voltage (vehicle electrical system voltage) before and after measurements are taken at the measuring points on the measuring adapter. Correct functioning of this adapter and also of the two other measuring adapters must be checked before they are used by means of resistance measurements. Only then can work start on the high-voltage components.

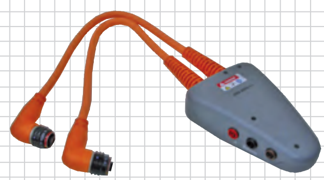
Adapter 2 (VAS 6558/1-2)

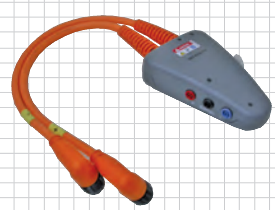
Adapter 2 is used to perform insulation measurements on the high-voltage lines and the power electronics. An insulation resistance meter for all-pole insulation measurement is connected to the measuring sockets for this purpose.

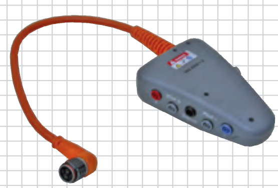
Adapter 3 (VAS 6558/1-3)

Adapter 3 is used to measure the insulation of the lines to the air-conditioning compressor and the connections (all poles).

Refer to the Workshop Manual for more information and instructions on taking measurements.


VAS 6558/1-1


VAS 6558/1-2


VAS 6558/1-3

METER
IN ACCORDANCE
WITH IEC 61010-1
54CJ

IEC mark of conformity

VDE mark of conformity

EU mark of conformity

USA mark of conformity

Canada mark of conformity

TÜV/GS symbol

!

Always use measuring and test equipment approved by the manufacturer. Further information can be found in the workshop literature.

Standardisation of measuring devices

The IECEE defines standard international test procedures and certifications for electrical equipment. Adopted standardized test procedures are performed by recognized certification authorities and validated with a globally recognized test certificate. This certificate confirms that a test sample from a product series has been tested successfully. The devices are marked accordingly. IEC test regulation 61010 is valid for high-voltage measurements:

Safety regulations applicable to hand-held accessories for measuring and testing

The VDE (Association of German Electrical Engineers) is a certification authority recognized by the IECEE. Measuring devices marked with the VDE symbol have therefore been tested in accordance with globally valid procedures and are authorized for international use. In some countries, additional requirements must be fulfilled and certified with the national mark of conformity.

Only measuring devices that bear the VDE mark of conformity comply with DIN VDE 0681-1 parts 2 and 4 and IEC 61010 and can therefore be used for taking high-voltage measurements.

Products that comply with directives valid within the EU are marked with the CE symbol (Conformité Européenne). In Europe, no other national marks of conformity are required but are often applied.

The mark of conformity from the USA includes the letters UL (Underwriters Laboratories Inc.).

Canada mark of conformity (Canadian Standards Associations).

In Germany, devices certified by TÜV bear additional marks of conformity that guarantee safe handling.

Competencies and responsibilities

Introduction

The introduction of hybrid technology at Porsche requires a re-evaluation of the qualification degree of the workshop personnel. Due to the varying nature of the work performed on hybrid-specific and conventional components in our vehicles, it makes sense to structure the qualification into different levels. Electrically instructed persons (Eip) or high-voltage technicians (HVT) employed in the workshop will share responsibility for the maintenance and repair of hybrid vehicles in the future.

High-voltage technician (HVT)

The high-voltage technician has the ability to check the function of all high-voltage components installed in the vehicle. If necessary, the technician can disconnect the high-voltage system and then check that there is no electric charge. If a vehicle cannot be de-energized, the technician can request the assistance of an electrically skilled person (Esp) to assume responsibility for completing the task. To do this, he must create a PTEC.

The technician is allowed to assign work on vehicles disconnected from the power that is defined in the workshop literature to electrically instructed persons, but must assume responsibility for the correct completion of the work. When the work is finished, the high-voltage technician is the only person permitted to start the hybrid vehicle again.

Electrically instructed person (Eip)

Electrically instructed persons are instructed of the dangers of handling hybrid components improperly. Under the instruction and supervision of the high-voltage technician, they perform defined tasks on the voltage-free system as well as tasks that do not require the disconnection of the high-voltage system.

Electrically skilled person (Esp)

Electrically skilled persons possess extensive knowledge of the dangers of electrical current as well as the hybrid technology used in Porsche vehicles. He has the ability to disconnect the high-voltage system using different methods to those described in the Workshop Manual (e.g. on accident vehicles) and is therefore allowed to perform work on live high-voltage systems. The manufacturer provides him with assistance if necessary. The HVT submits a request for assistance from an electrically skilled person by issuing a PTEC.

!

Please refer to the workshop literature to determine who is authorised to work on high-voltage vehicles and which tasks they are allowed to perform.

Employees not qualified for high-voltage work

Employees who do not have any of the qualifications mentioned above are not qualified to perform work on the high-voltage system. This applies to all remaining staff at the Porsche dealership. They are not allowed to work on hybrid vehicles and are instructed on how to deal with hybrid vehicles in the Porsche dealership as part of an internal company health and safety briefing held at least once a year.

Company operator/Superior

The first and foremost duty of the company operator is to prevent accidents in accordance with the relevant applicable guidelines on occupational safety.

The operator assumes responsibility for guaranteeing the qualification and motivation of his employees. He can nominate and appoint in writing technically skilled employees to perform certain duties. A successfully qualified high-voltage technician needs to be nominated and officially appointed in order to perform work on vehicles with high-voltage systems. The appointed high-voltage technician does not receive any technical instructions from his superior, i.e. he makes professional decisions independently. The company operator must implement appropriate procedures for selecting suitable employees:

- Duties must only be assigned to employees who possess the relevant qualifications.

The company operator is obliged to ensure that advanced training measures for obtaining the qualifications mentioned above are implemented and supervised accordingly.

- It is essential that only employees that have received adequate instruction are granted access to dangerous areas.

Consequences of occupational safety breaches

A breach of duties for occupational safety may have legal repercussions for individuals who neglect their dutiful obligations and/or for the company operator in the form of:

Criminal offense –>	Fine or custodial sentence
Infringement –>	Fine
Civil liability –>	Damages, compensation claims
Actions contrary to the labor law –>	Dismissal, warning

Such consequences can be expected in cases where particular blame is apportioned. In other cases, legislators often explicitly exempt the company operator from any liability.

Legal consequences resulting from infringements of occupational safety regulations usually require the apportioning of blame. Infringements are assigned to different categories:

Negligence	Breach of obligation to due diligence (consciously or unknowingly)
Gross negligence	Breach of basic obligations to due diligence, acting carelessly, ignoring basic regulations
Deliberate act	Hazarding specific consequences
Intent	Specific desire to harm third parties

The principle always applies: "Everyone pays the consequences of their actions."
This means that if an occupational accident occurs within the company, the following examples may also be considered in addition to the fault of the acting party:
- the conduct of colleagues contributed to the accident,
- superiors have fulfilled their personnel management duties,
- the company operator has fulfilled all organisational and personnel management duties.

Criminal liability may not apply exclusively to cases of intentional behaviour, but also in special cases where individuals only act negligently.
The following principle applies:
Ignorance is no excuse!