High voltage: Porsche electric motors explained

15/03/2021 With the pioneering drive of the Porsche Taycan, Zuffenhausen continues its tradition of innovation. This is how electric motors work, in detail.

Please sit back. If you fully depress the accelerator pedal of a Porsche Taycan Turbo S, you will experience 12,000 reasons to choose a stable seating position. The driver and passengers are pressed into the upholstery in a manner that almost takes their breath away when the top model of the electric sportscar unleashes its collective torque of 12,000 Nm on all four wheels at once (Taycan Turbo S (2023): Electric power consumption* combined (WLTP) 23.4 – 22.0 kWh/100 km, CO emissions* combined (WLTP) 0 g/km, CO2 class A). The concentrated power is discharged in full without any delay and the thrust from the two electric motors on the front and rear axles remains virtually unchanged up to top speed.

This dose of adrenaline is the active ingredient in Porsche's unique drive technology. It's no coincidence that the renowned Center of Automotive Management (CAM) declared the Taycan the world's most innovative model of 2020. At Porsche, innovation has always meant pushing technology to the extreme.

In this case, that means exploiting the potential of the electric drive in a way that no one has ever done before.

Steered wheelhub motors from Ferdinand Porsche

Porsche did not come up with this concept just yesterday – or even the day before. In fact, it was more than 120 years ago. At that time, a young Ferdinand Porsche achieved a world first when he developed electric vehicles with steered wheelhub motors. The possibilities offered by electromobility spurred on his sporting ambition, and his racing car became the world's first all-wheel-drive passenger vehicle.

The simple DC motors of yesteryear have long since been replaced by more sophisticated machines. However, the basic physical principle has remained the same: magnetism. A magnet always consists of a north and a south pole. Unequal poles attract; equal poles repel. On the one hand, there are permanent magnets, which are based on the interplay of elementary particles. On the other, magnetic fields also arise every time an electric charge is moved. To amplify the electromagnetism in play, the current-carrying conductor in an electric motor is arranged to form a coil. Electromagnets and – depending on the design of the motor – permanent magnets are arranged on two components. The stationary part is called the stator, the rotating part is the rotor, which turns when attractive and replusive forces are generated by periodically switching the electrical voltage on and off.

PSM instead of ASM

Not every type of electric motor is suitable for propelling a vehicle. Porsche makes use of the permanently excited synchronous machine (PSM). Compared to the predominantly used design – the cheaper asynchronous machine (ASM) – the PSM offers higher continuous output because it overheats less easily and therefore does not have to be turned down. Porsche's PSM is supplied and controlled via power electronics with three-phase AC voltage: the speed of the motor is determined by the frequency at which the alternating voltage oscillates around the zero point from plus to minus. In Taycan motors, the pulse inverter sets the frequency of the rotating field in the stator, thereby regulating the speed of the rotor.

The rotor contains high-quality permanent magnets with neodymium-iron-boron alloys that are permanently magnetised during the manufacturing process via a strong directional magnetic field. The permanent magnets also enable a very high degree of energy recovery through recuperation during braking. In overrun mode, the electric motor goes into regenerative mode while the magnets induce voltage and current into the stator winding. The recuperation performance of the Porsche e-motor is the best among the competition.

Hairpin winding: a special feature of the Taycan motors

Technology driven to its very limits: this Porsche gene is reflected in a special feature of the Taycan motors, known as the hairpin winding. Here, the coils of the stator consist of wires that are not round but rectangular. And unlike classic winding processes where the copper wire is obtained from an endless reel, hairpin technology is what is known as a forming-based assembly process. This means that the rectangular copper wire is divided into individual sections and bent into a U-shape, similar to a hairpin. These individual 'hairpins' are inserted into the stator laminations in which the winding is mounted in such a way that the surfaces of the rectangular cross-section lie on top of each other.

This is the decisive advantage offered by hairpin technology: it allows the wires to be packed more densely, thereby adding more copper to the stator. While conventional winding methods have a copper fill factor – as it is known – of around 50 per cent, the technology used by Porsche has a fill factor of almost 70 per cent. This increases power and torque with the same installation space. The ends of the wire hairpins are welded together by laser, creating the coil. Another important advantage is that the homogeneous contact between adjacent copper wires improves heat transfer and a hairpin stator can be cooled much more efficiently. Electric motors convert more than 90 per cent of the energy into propulsion. But just as in an internal combustion engine, the losses are converted into heat that has to be dissipated. That is why the motors have a cooling water jacket.

Culmination of Porsche expertise in the pulse inverter

In order to precisely control a permanently excited synchronous motor, the power electronics must know the exact angular position of the rotor. This is what the resolver is for. It consists of a rotor disc made of field-conducting metal, an exciter coil, and two receiver coils. The exciter coil generates a magnetic field that is transmitted via the encoder to the receiving windings. This induces a voltage in the receiving coils, the phase position of which are shifted proportionally to the rotor position. The control system can use this information to calculate the exact angular position of the rotor. This control system, known as the pulse inverter, is the culmination of Porsche expertise. It is responsible for converting the battery direct current at 800 volts into alternating current and supplying it to the two e-motors.

Porsche was the first manufacturer to implement a voltage level of 800 volts. Originally developed for the Porsche 919 Hybrid race car, this voltage now reduces weight and installation space in series production thanks to leaner cables, enabling shorter charging times. The electric motors reach up to 16,000 revolutions per minute. To make optimum use of this speed range for Porsche's signature spread between dynamics, efficiency and top speed, the front and rear drive units each have their own transmission. The Taycan is the first electric sports car ever to have a transmission with two shiftable gears on the rear axle, the first of which has a very short reduction ratio. On the front axle, an input planetary gearbox transmits power to the wheels.

These combine to give the Taycan Turbo S its mighty powers. At the front axle, the gear ratio translates the 440 Nm generated by the electric motor to around 3,000 Nm at the wheels. Some 610 Nm from the rear-axle motor are multiplied in first gear to about 9,000 Nm of axle torque. The task of the longer-ratio second gear is to ensure efficiency and power reserves at high speed. This is pioneering technology, applied to the smallest detail – and a continuation of Porsche's tradition of innovation in the age of the electric drive.

Info

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Consumption data

Taycan Turbo S (2023)
Fuel consumption / Emissions

WLTP*
Electric power consumption* combined (WLTP) 23.4 – 22.0 kWh/100 km
CO emissions* combined (WLTP) 0 g/km
CO2 class A Class

*Further information on the official fuel consumption and the official specific CO emissions of new passenger cars can be found in the "Leitfaden über den Kraftstoffverbrauch, die CO-Emissionen und den Stromverbrauch neuer Personenkraftwagen" (Fuel Consumption, COEmissions and Electricity Consumption Guide for New Passenger Cars), which is available free of charge at all sales outlets and from DAT (Deutsche Automobil Treuhand GmbH, Helmuth-Hirth-Str. 1, 73760 Ostfildern-Scharnhausen, www.dat.de).

Image Sublines

Path: High Voltage – Porsche electric motors explained/Images/img_1.jpg
Title: Porsche electric motor, 2021, Porsche AG
Subline: Powerhouse: the electric motor and two-speed gearbox (front) are arranged parallel to the rear axle. The power electronics are located on top.

Path: High Voltage – Porsche electric motors explained/Images/img_2.jpg
Title: Porsche electric motor, 2021, Porsche AG
Subline: Centrepiece: the stator of the e-motor essentially consists of circular sheet-metal discs layered into a tube and the copper coils. U-shaped bent wires are inserted into gaps in the tube and connected to each other.

Path: High Voltage – Porsche electric motors explained/Images/img_3.jpg
Title: Porsche electric motor, 2021, Porsche AG
Subline: Compact: the front-axle drive of the Taycan is designed to be even more space-saving than the drive unit in the rear. The motor and gearbox are arranged coaxially; the rotor, gearbox, and axle shafts are in line.

Path: High Voltage – Porsche electric motors explained/Images/img_4.jpg
Title: Porsche electric motor, 2021, Porsche AG
Subline: Flywheel mass: the rotor is filled with permanent magnets arranged in a V-shape.

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