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PRESS INFORMATION

Audi e-tron: recuperation and drive

Intelligent energy recuperation:
Top-level recuperation and brake system

Performance and efficiency – the Audi e-tron combines enormous power and a long range. The full-size SUV with fully electric drive has an output of up to 300 kW and accelerates from zero to 100 km/h *(0-62.1 mph)* in less than six seconds. In the WLTP test cycle, it covers more than 400 kilometers *(248.5 mi)* on one battery charge. One important factor here is the most innovative recuperation concept among all the competitors, which contributes to up to 30 percent of the electric SUV's range. It is assisted by a newly developed "brake-by-wire" brake system. The decoupling of the brake pedal and the hydraulic system enables a smooth transition between the engine brake and the conventional friction brake.

Recuperation with variable regulation

The long range in everyday operation is achieved thanks to numerous high-tech solutions that increase the efficiency of the Audi e-tron significantly. In addition to the intelligent thermal management and the low drag coefficient of 0.27 in combination with virtual exterior mirrors, the innovative recuperation system in particular is crucial here. It involves both the two electric motors on the front and rear axles selectively and the electrohydraulically integrated brake control system. For the first time, three different recuperation modes are combined: manual coasting recuperation using the shift paddles, automatic coasting recuperation via the predictive efficiency assist, and brake recuperation with smooth transition between electric and hydraulic deceleration. Overall, the Audi e-tron attains up to 30 percent of its range in normal operation through recuperation.

Active in over 90 percent of all decelerations: energy recuperation
The electric SUV can recover energy in two ways: by means of coasting recuperation when the driver releases the accelerator, or by means of braking recuperation when the brake pedal is depressed. In both cases, the electric motors function as a generator and convert the kinetic energy of the Audi e-tron into electric energy. The SUV recuperates up to 0.3 g via the electric motors alone – that covers over 90 percent of all decelerations. So, energy is returned to the battery in practically all normal braking maneuvers. The recuperation system's ability to react on an individual basis to the various operating states makes it so variable and efficient that the mechanical brake is rarely used. Because of this regulation strategy, the system is the most efficient on the market.

Beginning with a deceleration torque greater than 0.3 g, the Audi e-tron no longer recuperates energy only via the electric motors, but also uses the internally ventilated 18-inch wheel brakes with a six-piston fixed-caliper brake on the front axle and a single-piston sliding caliper on the rear axle. This results in short braking distances in all situations.

In case of a brake application at a speed of 100 km/h, for example, the Audi e-tron can recuperate electric power with a maximum of 300 Nm *(221.3 lb-ft)* and 220 kW; that corresponds to more than 70 percent of its operating energy input. No other series production model can achieve such a value. The electric SUV thereby comes close to the level of a Formula E racing car in the 2018/2019 season. It recuperates 100 percent of its operating energy input with a maximum of 250 kW of electric power.

While driving downhill, the Audi e-tron can recover almost all the energy it generates though the difference in height by means of recuperation. The battery is recharged while driving. This allows the electric SUV to achieve long ranges even in mountainous regions.

From freewheeling to a one-pedal feeling: electric deceleration
The driver can adjust the degree of coasting recuperation in three stages via paddles on the steering wheel. In the lowest setting, the Audi e-tron coasts with no additional drag torque when the driver releases the accelerator pedal. The car continues to roll forward. No electricity flows to or from the electric motor while the vehicle is moving. In level 1 (balanced – minimal deceleration) and level 2 (strong – high deceleration), the electric motors generate regenerative brake torque and produce electricity. The electric SUV reduces the speed noticeably – the driver can decelerate and accelerate using just the accelerator pedal. This creates the one-pedal feeling. There is no need to use the brake pedal in this case.

In addition to adjusting the recuperation manually via the steering wheel paddles, the driver can also select automatic mode in the MMI. The predictive efficiency assist then regulates the deceleration as needed and predictively, for example in relation to the route or vehicles in front. The driver can adapt the deceleration effect by selecting the desired recuperation level via the shift paddles. It remains active until the driver operates the accelerator pedal again.

In the case of electric deceleration, the system uses a quattro recuperation function developed specially by Audi to make an individual decision as to which axle contributes to the recuperation and to what extent. The drive control unit calculates the ideal distribution of the recuperation torque to both electric motors exactly and within a fraction of a second. In most cases, the electric SUV tends to use its rear electric motor to achieve the highest efficiency. If the driver demands more braking power than the rear electric motor can supply, the electric all-wheel drive redistributes torque as required to the front axle. This also happens predictively even before slip occurs in icy conditions or when cornering fast, or if the car understeers or oversteers. Only the Audi e-tron offers this combination of a holistically efficient operating strategy and recuperation with the electric quattro drive.

Supports an economic driving style: the efficiency assist

The efficiency assist is one of the numerous driver assistance systems that are available for the Audi e-tron. It helps the driver to drive economically, thereby contributing to increasing the range. The system uses radar sensors, camera images, navigation data and Car-to-X information to detect the traffic environment and the route. The driver is shown corresponding information in the Audi virtual cockpit and the optional head-up display as soon as it would be sensible to take the foot off the right-hand pedal.

If the driver has selected the automatic recuperation setting in the MMI, the information and automatic recuperation interact to form a convenient overall system. The system determines the ideal deceleration for the particular situation and recuperates energy in a way that is optimally adapted to the events.

By interacting with the adaptive cruise assist, the efficiency assist can also decelerate and accelerate the Audi e-tron predictively by evaluating sensor and navigation data as well as traffic signs. It automatically adjusts to the current speed limit, reduces the speed before corners, during turning and on roundabouts. The predictive system always maintains a driving style that reflects the driving program selected – from efficient to sporty – and uses the individual opportunities for recuperation.

Electrohydraulically integrated brake control system

Audi is the first manufacturer worldwide to use the electrohydraulically integrated brake control system technology in a series production vehicle with electric drive. Thanks to its compact design, this system weighs less than six kilograms *(13.2 lb)*, making it roughly 30 percent lighter than a conventional brake system, and allows the Audi e-tron to exploit its maximum recuperation potential in a targeted manner. The electric SUV decides whether to decelerate using the electric motor, the wheel brake, or a combination of the two depending on the driving situation.

Unnoticeable to the driver: the transition from electric to hydraulic braking

It is in the rare cases that the Audi e-tron uses its wheel brake, for example during maximum full-stop braking, that the powerful properties of the integrated brake control system really stand out. The control unit detects with how much force the driver is depressing the brake pedal and calculates how much braking torque is needed within milliseconds. If the recuperation torque is not sufficient, a displacement piston in the brake hydraulics generates additional pressure. Put into motion by an electric spindle drive, it pushes brake fluid into the brake lines and generates brake force through the conventional friction brake in addition.

The transition between electric and hydraulic braking is smooth and homogeneous, so the driver does not even notice it; the brake forces remain constant. Using a pressure-resistant element, a second piston generates the familiar pedal feeling for the driver’s foot. Thanks to this brake pedal simulator, the driver is not affected by what is happening in the hydraulics. In the case of ABS braking, pressure buildup and reduction are not noticeable in the form of irritating hard pulsations.

Lightning-fast pressure buildup: impressively short braking distances

The new electrohydraulic actuation allows the brake control system to build up brake pressure for the wheel brakes with great precision and roughly twice as fast as a conventional system. This enables a larger air gap, i.e. a greater distance between the brake pad and brake disk, to be set. This minimizes possible friction and heat generation and contributes actively to the long range of the Audi e-tron.

When automated emergency braking is performed, there are only 150 milliseconds – ever so slightly more than a blink of the eye – between the initiation of the brake application and the presence of maximum brake pressure between the pads and disks. Thanks to this rapid pressure buildup, the electrohydraulically integrated brake control system shortens the braking distance by up to 20 percent compared with a conventional brake system. The power electronics modules of the electric motors also contribute to this. Each millisecond, they counteract the vibrations that can occur on the wheels due to brief losses of contact during strong deceleration and increase the braking distance as a result.

The wheel brakes are seldom needed in normal operation, which has a positive effect on wear. The Audi e-tron is equipped with a brake cleaning function that helps the steel disks to remain free of oxidation as far as possible. During deceleration, it automatically uses the friction brake instead of recuperation at specific intervals. This way, the system is always in optimum operating condition.

Driving pleasure in the age of electric cars

The Audi e-tron offers driving pleasure in a new dimension. Its two electric motors drive the electric SUV powerfully, free of emissions, and almost silently, with a system output of up to 300 kW. The high-voltage battery stores 95 kWh of energy to provide a range of over 400 kilometers *(248.5 mi)* in the WLTP cycle. The Audi e-tron is thus predestined for long distances.

Efficient and robust: asynchronous motors
The two asynchronous motors of the Audi e-tron have a peak performance of 265 kW and develop 561 Nm *(413.8 lb-ft)* of torque. They do not produce any electrically induced drag losses in the deenergized condition, which makes them highly efficient. Not only are they very light due to the aluminum rotor, they also have further advantages: They require little maintenance and are particularly robust. Furthermore, no rare earth elements are used in the production of the electric motors.

The asynchronous motors can deliver their peak performance for up to 60 seconds. This way, they allow the vehicle to accelerate from a standstill to the electronically limited top speed of 200 km/h *(124.3 mph)* several times consecutively without output losses. The start-off performance, for example at a traffic light, is comparable to that of a sports car. The maximum drive torque is present within fractions of a second and provides enormous torque. The front electric motor, which is positioned parallel to the axle for the purpose of optimum packaging, achieves a peak output of 125 kW at 247 Nm *(182.2 lb-ft)* of torque. The rear, coaxially positioned motor reaches an output of 140 kW with a torque of 314 Nm *(231.6 lb-ft)*. Two-stage planetary gearboxes with one gear range transfer the forces to the axles via the differentials.

Asynchronous motors can increase their output for a short period of time. By shifting from drive range D to S and fully depressing the right-hand pedal, the driver can activate boost mode. It is available for eight seconds. Here, the drive produces 300 kW of system output and 664 Nm *(489.7 lb-ft)* of torque. The Audi e-tron sprints from 0 to 100 km/h *(62.1 mph)* in less than six seconds. The forces are distributed as follows between the electric motor at the front axle and the one at the rear axle: 135 kW of boost output with 309 Nm *(227.9 lb-ft)* of torque at the front, 165 kW with 355 Nm *(261.8 lb-ft)* at the rear.

Important factor: thermal management
Thermal management plays a crucial role in the performance of the electric motors. Audi has implemented a particularly effective and efficient solution here. The thermal management system of the Audi e-tron comprises four circuits that can be connected in various ways as required. It heats and cools the interior and the high-voltage battery while also cooling the electric motors including their rotors, the power electronics, and the charger.

The rotors, which reach up to 13,300 revolutions per minute during real vehicle operation, consist of magnetically conductive electrical sheets and lightweight, high-purity aluminum. Coolant flows through the inside of the shafts to ensure that the temperature does not exceed 180 degrees Celsius. Being the hottest components in the powertrain, they provide the thermal management system with a large quantity of heat.

The standard heat pump uses the waste heat from the electrical components. Up to 3 kW of the actual power losses are used efficiently to heat and air-condition the interior. Depending on the outside temperature, that can boost the Audi e-tron's range by up to ten percent.

The high-performance thermal management system offers Audi e-tron drivers numerous advantages. It guarantees fast direct-current charging with up to 150 kW at the quick charging stations in the Ionity network. It also contributes to the long service life of the battery and ensures reproducible driving performances even at high loads.

Current transformers: power electronics modules

Every motor in the Audi e-tron is supplied and controlled by its own power electronics module, which works together closely and extremely dynamically with the drive control unit. All requests come together in the drive control unit – from the accelerator pedal, the brakes, or the electric all-wheel drive. The power electronics modules read in sensor data 10,000 times per second and output current values for the electric motors. This results in the optimum use of output during dynamic vehicle operation in particular. Some functions, such as vibration damping and slip control functions, are integrated in the power electronics directly. This enables the deceleration-free translation of interventions and improves, for example, the vehicle's ability to accelerate on icy roads significantly.

The two structurally identical power electronics modules are positioned on the housings of the electric motors and are integrated into the thermal management system of the drive system. They take up little space, and each weighs only eight kilograms *(17.6 lb)*; this is also thanks to their aluminum housing. The pulse width modulating inverter, its central component, converts the direct current from the battery into three-phase current. If the electric motors operate as the generator during recuperation, it converts the generated three-phase current into direct current and feeds it back to the battery.

Technology lexicon on recuperation and drive

Recuperation

Recuperation refers to the use of kinetic energy during deceleration. An electric traction motor in the vehicle turns into a generator when it is pushed and the rotor moves more quickly than the stator's rotating field. A distinction must be made between coasting recuperation, which takes place when the driver's foot releases the right-hand pedal, and braking recuperation, when the driver depresses the brake pedal. Coasting recuperation can take place automatically via the predictive efficiency assist. It regulates the deceleration as needed and predictively, for example in relation to the route or vehicles in front. Alternatively, the driver can regulate the degree of deceleration manually using the shift paddles on the steering wheel. During coasting and braking phases, the generator converters the kinetic energy into electric energy and feeds it into the battery. Overall, the Audi e-tron attains up to 30 percent of its range through recuperation.

Electrohydraulically integrated brake control system

With the electrohydraulically integrated brake control system, Audi is presenting a world premiere in a series production vehicle with an electric drive. The wheel brakes are actuated hydraulically, the reinforcement is actuated electrically, and the activation is actuated electronically. The control unit detects with how much force the driver is depressing the brake pedal and calculates how much braking torque is needed within milliseconds. If the recuperation torque is not sufficient, hydraulic pressure for the conventional friction brake is generated in addition. Put into motion by an electric spindle drive, the displacement piston pushes the brake fluid into the brake lines. The transition from the engine brake to the pure friction brake is smooth, and the driver does not notice it. A second piston generates the familiar pedal feeling for the driver's foot by means of a pressure-resistant element. Thanks to this brake pedal simulator, the driver is not affected by what is happening in the hydraulics. In the case of ABS braking, pressure buildup and reduction are not noticeable in the form of irritating hard pulsations.

The electrohydraulic brake system is activated when the driver depresses the left-hand pedal so hard that the deceleration exceeds 0.3 g; otherwise, the Audi e-tron decelerates through recuperation via the two electric motors. Even at a very slow speed, such as during maneuvering, it decelerates via the wheel brakes because this is more efficient than electric braking in this case. Otherwise, the electric motor would have to use valuable battery current to decelerate actively at low rotational speeds.

The "brake-by-wire" technology of the electrohydraulically integrated brake control system enables a larger air gap, i.e. a greater distance between the brake pad and brake disk, to be set. This minimizes possible friction and heat generation and contributes actively to the vehicle's long range.

In dangerous situations, the electrohydraulically integrated brake control system builds up brake pressure around twice as fast as a conventional brake system. Maximum brake pressure is thus present after just 150 milliseconds. This is barely more than a blink of the eye and creates impressively short braking distances.

Predictive efficiency assist

The efficiency assist helps the driver to drive preemptively and save fuel. The system works together closely with adaptive cruise control or the adaptive cruise assist. It accesses predictive route data from navigation and Car-to-X information. In order to detect traffic signs and other vehicles, the efficiency assist uses the front camera as well as data from the front and rear-facing radar sensors.

The driver is shown corresponding information in the Audi virtual cockpit and the head-up display as soon as it would be sensible to take the foot off the right-hand pedal. Symbols for speed limits, curves, roundabouts, towns, or downhill slopes that indicate to the driver to slow down are displayed on the basis of the route data. The Audi e-tron recuperates automatically, depending on the situation.

If the cruise assist is switched on or the ACC is activated, the efficiency assist regulates actively: It decelerates and accelerates predictively and adapts the speed to the course of the road and the traffic situation, while also taking vehicles driving in front into account. The predictive system always maintains a driving style that reflects the driving program selected – from efficient to sporty – and uses scope for recuperation. The driver can override the system by accelerating and braking at any time.

Asynchronous motor

A three-phase asynchronous motor comprises two major parts: the outer, fixed stator and the rotor contained therein. The stator is a sheet package consisting of thin, magnetically conductive electrical sheets. Inside these are copper wire coils to which the three three-phase current phases from the power electronics are connected. When a voltage is applied to them, a circumferential (rotating) magnetic field is produced. The stator's rotating field induces a further magnetic field in the rotor – the rotor is carried along with the excitatory rotating magnetic field of the stator with a low rotational speed difference, i.e. asynchronously. If the rotor turns more slowly than the rotating magnetic field, the electric motor in the car works as a traction motor. In the opposite case, it becomes a generator and converts kinetic energy into electrical energy. The asynchronous motors do not produce any electrically induced drag losses in deenergized condition, which makes them highly efficient. Not only are they very light due to the aluminum rotor, they also have further advantages: They require little maintenance and are particularly robust. Furthermore, no rare earth elements are used in the production of the electric motors.

Peak performance

Peak performance refers to the highest output of the electric motors, which can be delivered for up to 60 seconds, several times consecutively, and without output losses. The peak performance of the front electric motor is 125 kW, with a torque of 247 Nm *(182.2 lb-ft)*. The values for the rear motor are 140 kW and 314 Nm *(231.6 lb-ft)*.

Boost performance

Asynchronous motors can increase their output for a short period of time. The boost is available for a maximum of eight seconds; during this time, the output of the front electric motor increases from 125 to 135 kW, while that of the rear motor increases from 140 to 165 kW. This constitutes an overall increase by 13 percent to 300 kW in total. The torque is also increased considerably by just over 18 percent, from 561 *(413.8 lb-ft)* to 664 Nm *(489.7 lb-ft)*.

Power electronics

The high-voltage battery delivers direct current; the electric motors use three-phase current, which is why every electric motor is connected to a power electronics module that converts the electricity. With a volume of 5.5 liters and weighing eight kilograms *(17.6 lb)*, the power electronics modules of the Audi e-tron are very compact. Both include a processor for controlling the electric motor and are integrated into the thermal management system for the electrical units. They are extremely dynamic, reading sensor data 10,000 times per second and outputting current values for the electric motors.

Heat pump

A heat pump can heat and cool very efficiently by absorbing heat from the environment. In the Audi e-tron, it uses the waste heat from the electrical components to transport up to 3 kW of thermal energy. The heat pump is not a separate physical component, but rather the demand-driven connection of the coolant circuit and the low-temperature cooling circuit.