How does regenerative braking work?

Regenerative braking systems recover as much kinetic energy as possible and store it as electrical energy. When braking, the vehicle's electric motor functions as a generator, producing electricity and feeding it into a high voltage battery.

How effective are regenerative braking systems and why are they so important for electric and hybrid vehicles?

In coming years, the efficient utilization of energy will be a major challenge. Regenerative braking systems help to lower consumption in hybrid vehicles and reduce their carbon footprint. They can also increase the range of electric vehicles, making them suitable for everyday use.

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Printed in Germany
292000P0SM-C/CCA-201109-En

125 Years Bosch 1886–2011

In 2011, the Bosch Group is celebrating a double anniversary: the 125th anniversary of the company's establishment, and the company founder's 150th birthday. This is cause for more than mere retrospection – it prompts us to show how the company's past fuels its future. The history of the company has had its ups and downs, but at the same time has always been vibrant. We see this history as one that drives us forward to new – and above all beneficial – achievements.

Chassis Systems Control
Reduce consumption. Protect the environment.
Regenerative braking systems

BOSCH
Invented for life

125 Years Bosch 1886–2011

Regenerative braking systems
increase range and reduce CO_2 emissions

Alternative drive technologies are becoming increasingly important.
Strict emissions regulations and the finite nature of fossil fuels make alternative drive concepts an inevitability. This is why Bosch is continuing to enhance the combustion engine in parallel with concerted efforts to electrify the powertrain.

The future viability of electrical powertrains is greatly dependant on their range and battery storage capacity. Electric vehicles will achieve ranges that are sufficient for everyday use only with efficient batteries, intelligent energy management and the recovery of braking energy.

Charge the battery by braking.
When braking in a conventional vehicle, the friction brakes convert much of the kinetic energy into heat that is emitted unused into the environment. Hybrid and electric vehicles with regenerative braking system are different in that. They recover some kinetic energy via the electric motor and store it as electrical energy in a high-voltage battery. This process is known as recuperation or regenerative braking. The electric motor can then use this stored energy when driving off or accelerating.

Regenerative braking makes it possible to increase the range of electric vehicles and reduce the fuel consumption and carbon footprint of hybrid vehicles.

Which hybrid and electric vehicles are available?

Mild hybrid: The combustion engine is supported by a low-powered electric motor. The vehicle cannot run purely on electrical power.

Full hybrid: The vehicle is mainly powered by a combustion engine. It can be driven short distances using electrical power.

Plug-in hybrid: The vehicle is powered by a combustion engine but can be driven longer distances using purely electrical power. The high-voltage battery can be charged directly from a home electrical socket using a charger.

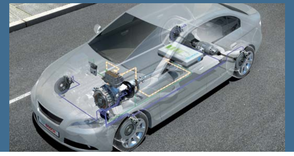
Electric vehicle: The vehicle is powered solely by an electric motor. The high-voltage battery can be charged from a home electrical socket.

Electric vehicle with range extender: The vehicle is powered solely by an electric motor. A small combustion engine can charge the battery as needed during vehicle operation.

Recover and store
energy.

The friction brake converts kinetic energy into heat that is emitted into the environment.

The generator transforms kinetic energy into electrical energy, which is stored in a high-voltage battery.



Kinetic energy generates electrical energy.
When braking in a hybrid or electric vehicle, the electric motor switches to generator mode. The wheels transfer kinetic energy via the drivetrain to the generator. The generator turns in a similar way to a bicycle light generator transforming part of the kinetic energy into electrical energy, which is then stored in a high-voltage battery. At the same time, generator resistance produced from the electricity created, slows the vehicle. When more braking torque is required than the generator alone can provide, additional braking is accomplished by friction brakes.

Practical benefits.
In many situations the generator's braking power is sufficient to slow the vehicle as desired by the driver. As a result, the friction brake is used less often, for example, in instances of very rapid deceleration, at very low speeds and when stationary. Regenerative braking contributes toward increasing the range of electrical vehicles. It helps to save fuel in hybrid vehicles and to reduce emissions of CO_2 and pollutants, particularly in urban traffic situations involving frequent braking and acceleration. In addition, using the generator for braking also reduces brake wear and the build-up of brake dust.

Energy recuperation: a complex process.
Regenerative braking systems control the interaction between friction brakes and the generator to guarantee efficient energy recuperation. They also ensure that deceleration behavior and pedal feel are identical to conventional braking systems.

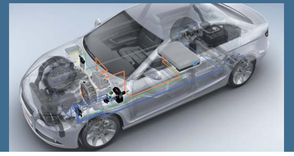
The generator's braking potential is dependent on the engine driving speed. At low engine speeds, maximum brake torque is available. At high speed or very low speed, e.g. just before coming to a stop, sufficient brake torque cannot be provided meaning the friction brake must be activated. Generator brake torque is proportional to the generator's output and is also influenced by the battery's level of charge. Brake torque from the generator is only available when the high-voltage battery is not fully charged.

Brake torque is distributed between the friction brakes and the generator, taking safety, comfort and efficiency criteria into consideration. If the vehicle becomes unstable, it is usually decelerated solely via the friction brake, as wheel-specific interventions of the Antilock Braking System (ABS) or Electronic Stability Program (ESP®)* are required.

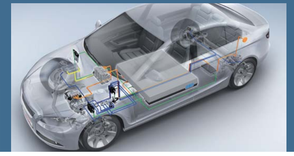
*Electronic Stability Program (ESP®) is also known as Electronic Stability Control (ESC)

Tailor-made
for the future.

Hybrid vehicle with vacuum-based regenerative braking system



Electric vehicle with vacuum-independent regenerative braking system



Regenerative braking systems from Bosch.
Vehicles that are mostly powered by combustion engines, such as mild hybrids and full hybrids, produce vacuum which can be used by conventional brake boosters. In contrast, plug-in hybrids and electric vehicles are not able to provide sufficient vacuum for brake boosters to operate. For this reason, the range of products offered by Bosch includes vacuum-based and vacuum-independent regenerative braking systems tailored to meet the individual requirements of various drive concepts.

Vacuum-based entry-level version.
In the entry-level version, the standard braking system is slightly modified and meets low recuperation requirements. The brake pedal is connected directly to the vacuum brake booster as normal. The vehicle's brake control system is enhanced with special software and is used as a control unit for regenerative braking.

When braking, braking torque is called for from the electric motor generator depending on the position of the brake pedal. If the driver brakes only lightly, the vehicle will be decelerated using the braking effect of the electric motor. When braking more heavily, friction brake torque is generated in addition to the generator brake torque. The driver can compensate for minimal fluctuations in deceleration, e.g. just before the vehicle comes to a stop, by using the brake pedal.

Vacuum-based version for greater demands.
Bosch also provides vacuum-based regenerative braking systems which make greater levels of recuperation possible. Modifications to the ESP® hydraulic unit allow the friction brake torque to be continuously adjusted to the current generator brake torque in order to maintain the desired total brake torque. This is known as torque blending. The process is controlled by software in the ESP® and is imperceptible to the driver.

Vacuum-independent version for the highest demands.
Vacuum-independent regenerative braking systems fulfill the highest level of recuperation and are particularly suitable for plug-in hybrids and electric vehicles. The conventional vacuum brake booster is replaced by an electro-hydraulic brake actuation unit and a brake-pressure modulation system. The brake pedal and brake booster are decoupled, allowing the generator's braking potential to be fully exploited. The friction brakes are only used for deceleration when the generator brake torque is no longer sufficient. Thanks to torque blending, energy recuperation during braking is virtually imperceptible to the driver.

Which regenerative braking system is suitable for which vehicle?

Bosch provides tailor-made regenerative braking solutions for hybrid and electric vehicles. The portfolio includes both vacuum-based systems and vacuum-independent regenerative braking systems.