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Magnetic braking and single-pedal speed control

The most revolutionary aspect of modern electric vehicles, from a driver's perspective, is almost certainly single-pedal speed control. Single-pedal speed control is simply the control of both acceleration and deceleration with a single pedal. Traditionally this has been done with two pedals, as the slowing system (hydraulic friction brakes) was always completely separate from the motive system (the internal combustion engine).

The electric motor as a braking force

The motor (or motors) that power electric vehicles (EVs) rely on internal magnetic forces to accelerate the car; those magnetic forces can also be reversed to slow the car. The basic principle is the same as with your ordinary refrigerator magnet. As you bring the magnet closer to the refrigerator, the magnet pulls (accelerates) your hand toward the metal door. The closer you get, the more powerful the magnetic field, the stronger the force. When you try to pull the magnet off, it resists (magnetic braking).

Electric motors are actually much better suited to powering cars than internal combustion engines. Electric motors' power and torque extends from a stand-still to the top speed of the car, without the need for any gear shifts. So in virtually all street EVs today, the electric motor is always directly connected to the drive wheels via a single-speed transmission — there's no clutch, and no "neutral" (although Teslas have an "N" position that selects an *electrical* neutral — no power moving into or out of the motor, but it's not a *mechanical* neutral). When the motor turns, the wheels turn. When the car is rolling, the motor is turning. The speed of the car is directly proportional to the speed of the motor.

A single pedal can control the motor speed — up or down, so it makes no sense to control the motor with two different pedals (the "accelerator" and a brake pedal). One pedal controls the speed — call it a "speed pedal." It controls deceleration as much as it does acceleration, and of course no "gas" is involved. With single-pedal speed control, the driving experience is therefore very much enhanced, as it is no longer necessary to shuffle your foot back and forth between two pedals to control the car's speed.

Terminology

Using magnetic forces in the motor to slow an EV has most often been labeled "regenerative braking," or "regen" for short. It's also been called "brake energy recuperation" (more correctly: *kinetic* energy recuperation). When you lift up on the speed pedal (and the car is rolling and therefore rotating the motor) the momentum of the car now turns the motor. The magnetic forces inside the motor are reversed, turning it into a generator that *charges* the battery (to say it *regenerates* the battery would be a misuse of the common meaning of that word). In essence, it converts the kinetic energy of the car into electrical energy. Part of the electrical energy that was expended accelerating the car, or moving it up a hill, can then be recouped when decelerating or driving down the hill.

So what should we call this new form of braking — something simple, descriptive, and easily understood by an EV novice? With conventional brakes, it is *friction* that slows the car (creating waste heat, a coating of black dust on your wheels, and regular income for auto service departments). With your EV, it is *magnetic* force that slows your car (creating electrical energy to charge your battery as a side-effect). Hence, *friction* braking and *magnetic* braking.

The psychology of magnetic braking

Magnetic braking is new. It's much more technically sophisticated than the mechanics of hydraulic pistons pressing brake pads against a brake disc. And unlike friction brakes, magnetic brakes are *invisible*.

It's no wonder that magnetic braking is so seldom explained. But braking is arguably much more important to a driver than how fast a car will accelerate, and a year-long study of magnetic braking from a user's perspective revealed that drivers found it very appealing.

The study found that participants greatly preferred magnetic brake activation by accelerator (versus brake pedal), and "quickly adapted to driving with one pedal." Many of the drivers acclimated to the single-pedal speed control by the end of their first test drive.

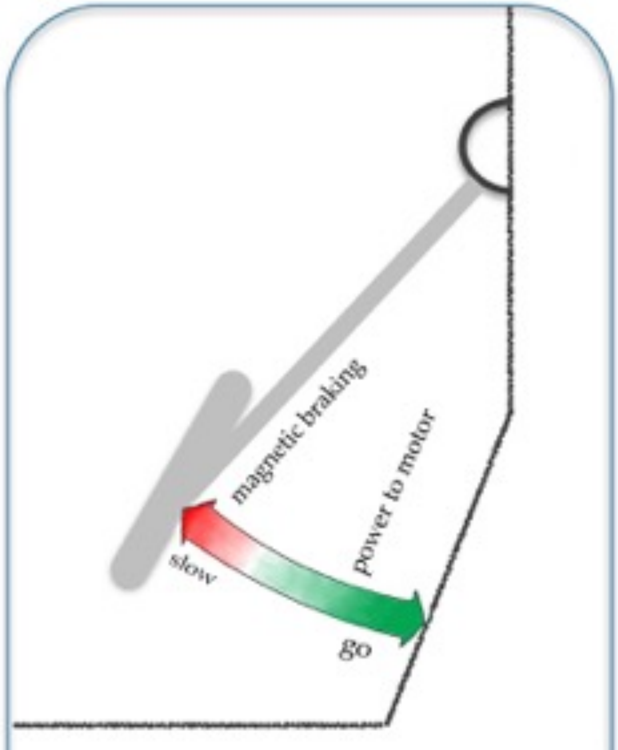
In the study, a great majority of the drivers "liked the strong regenerative braking after they became accustomed to it, and tried to use the friction brakes as little as possible." In a 2012 study, test drivers found EVs with stronger magnetic braking to be "more directly controllable than EV concepts with [weaker regen]."

Tesla allows the driver to select two levels of magnetic braking strength, toggled on the touchscreen between "standard" and "low." The lower setting simulates a conventional car's mild engine drag when the driver lifts off the accelerator. While the experience will be more familiar to new EV drivers, it negates the advantages of single-pedal speed control. It also sends much less energy back to the battery, reducing the car's efficiency.

A few drivers in a later study mentioned that in the beginning they "often stopped too early, for instance, at a traffic light as they underestimated the deceleration of the system. However, they reported that after the initial adaptation phase they managed to decelerate quite accurately as they used the pedal more sensitively." In other words, they discovered they could modulate the braking force by not fully lifting off the pedal.

Pedal control

The illustration below shows that the forward part of the speed pedal travel sends power to the motor, and the rearward part of the pedal travel slows the car. But don't overthink this control mechanism—just drive the car intuitively. The pedal controls the speed—push down some to go faster, let up some to go slower, or put your foot at a spot that maintains a constant speed. It's seamless; there's no shifting your foot from one pedal to another to inform you when you go from power to braking. Because the motor is always directly connected to the wheels, you won't readily be able to tell where the transition is.



Single-Pedal Speed Control

Remember, just as pushing the pedal to the floor will give you maximum acceleration, releasing the pedal completely will give you maximum magnetic braking. For everything in between, your foot needs to stay on the pedal. Let up a little — less braking; let up more — stronger braking.

You may still need to apply the friction brakes for the last little bit before coming to a complete stop, and because the friction brakes can be much more powerful than the magnetic brakes, you will also need to apply the friction brakes for sudden stops.

Four-wheel versus two-wheel magnetic braking

Magnetic braking only works through the wheels that are directly connected to the motor. With rear-wheel drive EVs, the magnetic braking is through the rear wheels only. Since the front wheels are the most effective at braking (due to weight shift on deceleration), the effectiveness of RWD cars' magnetic braking is limited during difficult braking situations, when the car's stability control system may become active.

All-wheel drive (Dual-Motor) Teslas, on the other hand, provide balanced four-wheel magnetic braking (and more even tire wear). As implemented, their magnetic brakes are independently controlled front and rear; resistance is automatically adjusted at each axle to match conditions. It's a compelling reason to choose the Dual-Motor option.

The future

Single-pedal speed control is certainly not going away. After getting used to it, drivers are not going to accept anything less. It's that addictive!