Pictures of the Future | Electric Vehicles

Power where it's Needed

Wheel-hub motors allow electric drive units to be located where their torque is needed: at the wheel. Here, they can also be used as brakes. In combination with a new system architecture, these motors not only enhance efficiency and safety, but also open the door to personalized cars through software upgrades. Researchers at Siemens have already developed an initial test vehicle.

Siemens researchers equipped a Roding sports car with two wheel-hub motors. The electric drive units fit into the rims and produce a total torque that can reach 2,500 newton meters.

The vehicle test rig at Siemens Corporate Technology (CT) in Munich, Germany, doesn't look much like an automotive facility — there are no oil puddles, black exhaust spots, or gasoline smells. But that's not surprising, given that this is a place where clean electric cars are tested. Right now, a sleek green-and-white open-top sports car is suspended on the lift at head level as if it were trying to emphasize its outstanding aerodynamic properties. Siemens developed the car with the support of Germany's Environmental Ministry and in cooperation with Roding Automobile, TRW Automotive, and other small companies. At the test rig, the vehicle's axles are connected to four giant, external air-cooled electric motors whose bulk stands in sharp contrast to the car itself — a typical test arrangement for simulating every type of driving situation by altering the rotation of each individual tire.

The special feature of this electric car is its two wheel-hub motors, which are small enough to fit into the vehicle's rims. The first electric cars with wheel-hub motors actually came on the scene 112 years ago — one example being the Lohner Porsche, which was presented at the Paris World's Fair in 1900.

A wheel-hub motor is the ideal drive unit because it can be installed exactly where torque is needed: in the wheel. Size is not really the technical issue here; the important thing is to make the motor as tightly sealed as possible, despite its freely moving parts, so as to ensure that it is not damaged by dirt or moisture. For a long time there were concerns that such a large mass at the wheel could have a detrimental effect on handling, and that the motor itself, which has no shock-absorbing capabilities, could be damaged if it hit the ground on uneven surfaces. Tests showed that this concern was unfounded, and it might even be possible to install springs directly at the wheel in the future.

Wheel-hub motors take up practically no space in the vehicle interior — a feature that opens up completely new opportunities for designers. "Whereas a conventional vehicle has to be built around the power train, cars with wheel-hub motors make it possible for us to explore new approaches," says Prof. Gernot Spiegelberg, Director of Electric Mobility Concept Development at Siemens Corporate Technology. "Thanks to this development, we can now design a vehicle to offer optimal ergonomics and handling without having to worry about where we're going to put the engine."

Wheel-hub motors not only propel the vehicle; they also serve as reliable electric brakes.

The best part is that there is no need for any heavy, energy-guzzling camshafts, transmissions, or differentials. Most electric vehicles also don't require a clutch or gears; the wheel-hub motors in the roadster test vehicle deliver the necessary power right from the start and can accelerate the car to 160 kilometers per hour with a torque of 1,000 newton meters (and as much as 2,500 newton meters for short spurts) without any gear changing. The system also recovers almost all of the potential and kinetic energy released in 70 percent of braking maneuvers.

"High speeds weren't the objective here, though," says Dr. Gunter Freitag, who headed the team that developed the CT motor. "That's why we electronically limited the vehicle's top speed to 120 kilometers per hour. It was more important for us to achieve very high efficiency at partial engine loads. We're presenting the technology in a sleek sports car, but the goal of our development activities is to create an urban vehicle, which would drive in the medium-load range most of the time."

Freitag actually doesn't like it when people refer to his wheel-hub drive unit as a "motor." He believes "machine" is a better term, since the motor also serves as a brake. The high performance of each of the two motors (63 kilowatts in continual operation; 120 kilowatts maximum) results in a total output of 325 horsepower. This is very important, because that power is available even when the motor acts as a brake and a generator for producing electricity that is then stored in the battery. The vehicle's electric-motor braking system is therefore powerful enough to generate the legally required 30 percent of total braking force that will bring a vehicle to a stop if the mechanical braking system fails.

Regenerative braking is now a standard feature in electric vehicles — but Siemens engineers are moving far beyond today's technology with their wheel-hub machine. Up until now, electric car developers have always set a constant drag torque that begins braking the vehicle when the driver takes his or her foot off the gas pedal. As soon as the driver engages the brake, normal friction brakes kick in and convert a relatively large portion of the kinetic energy into heat that goes unused.

In the Siemens concept, the vehicle initially brakes only electrically; the conventional fric-

Siemens researcher Dr. Gunter Freitag (left) inspects a wheel-hub drive, which can also be used as an electric brake.

Experts at Siemens can simulate any driving situation with their test rig by altering the rotation of each wheel.

tion brakes aren't used until more than 30 percent of the maximum braking force is required. "Experience has shown, however, that this isn't necessary in more than 70 percent of all braking maneuvers," Freitag explains. "In other words, we can recover as much as 80 percent of the kinetic energy produced from braking in such cases." As Freitag points out, the driver doesn't notice any of this "brake blending." This innovative technology, coupled with a 19.4-kilowatt-hour lithium-ion battery, give the Roding roadster a range of approximately 120 kilometers.

Systems Approach. Obviously, the roadster's technology makes sense only if each motor is controlled solely by electronic systems. Spiegelberg is convinced that the transition to electric drives will force engineers to rethink everything in terms of systems rather than components, as has traditionally been the case. "The current transition from combustion engines to electric drives gives us an opportunity to reinvent the entire vehicle nervous system, so to speak," he explains. This development will also greatly improve safety and comfort. For example, all control systems could be linked and could activate themselves without the driver having to do anything.

This will be especially true in the future when each wheel will be equipped with a motor that can be controlled individually. Whereas today's anti-lock systems react only passively to blocked wheels by reopening the brakes, the wheel-hub motors can be made to brake so precisely that none of the wheels lock. This will also make it possible to maneuver through curves more safely at higher speeds.

The transition to electric drives offers the opportunity to reinvent the entire vehicle nervous system.

"If every wheel has a drive unit, you can design a car that will react extremely fast as it negotiates a sharp curve at high speed, because each motor automatically accelerates exactly the way it should. On a highway, the same vehicle will handle like a smooth and stable sedan — and all of this will be done with just the push of a button," Freitag explains. Experts refer to this as torque vectoring.

In the not-too-distant future, it will be possible to not only integrate drive units, brakes, and shock absorbers into each wheel, but also a steering system.

Now consider what would happen if the two front wheels turned in and the two rear wheels shifted out simultaneously. This wouldn't make any sense — at least not if a conventional vehicle were involved. But if the left wheels move forward and the right ones move back, the car would rotate in place. That would be good news — and not just for new drivers who have to make U-turns in three maneuvers today.

It would also be possible, of course, to turn all four wheels to the right in a right curve, which would allow you to get into even the tightest parking spaces — perhaps with the help of a parking assistant.

Drive-by-Wire. All of these concepts inevitably lead to the following question: Who will actually drive tomorrow's cars — people or machines? In other words, will our vehicles become robots?

"There's a new concept that will enable the safe and simple activation of future holistic driver assistance systems that manage braking, steering, and propulsion, among other things," says Dr. Michael Armbruster from CT,, who received his PhD from the Institute of Air Vehicle Systems at the University of Stuttgart. Before joining Siemens, Armbruster played a major role in transferring the fly-by-wire control concepts in modern aircraft into electronically-controlled and completely fail-safe systems for ground vehicles.

Such systems, however, require new vehicle control and communication concepts. In drive-by-wire systems, wheels are not turned mechanically, but are instead positioned via electric signals — an arrangement that allows for the incorporation of every possible type of electronic assistance system. Cars equipped with such a system could park themselves, brake autonomously in dangerous situations, and automatically assist drivers in moving through road construction sites. The numerous potential driver support options enabled by innovative driver assistance systems will become even more important in the future, as an increasing number of older individuals will also want to remain mobile. It's even conceivable that cars will be able to drive completely on their own.

Drive-by-wire can also be used in vehicles with combustion engines, of course. But this requires existing components to be gradually replaced or linked. The changeover to electric drive systems basically offers design engineers the opportunity to recreate system technologies whose efficiency can be exploited especially well when the drive systems, brakes, suspension, and steering are integrated into each wheel and consistently and safely controlled.

But if this vision is to become a reality, electronic systems will have to be one hundred percent reliable and hardware will therefore have to be redundant. Siemens researchers distinguish between hardware and functions in their concept. Their view is that a control unit doesn't need to know which hardware implements its commands. Thanks to this separation of hardware and function, it is possible to make software so scalable that new functions can be added at any time through a plug-and-play arrangement.

Siemens engineers are currently working with several research and industrial partners to turn their vision into reality. With support from Germany's Ministry of Economics and Technology, these organizations plan to develop and test a new system architecture for electric vehicles by the end of 2014.

This architecture will make it possible for motorists to add assistance and safety systems to their vehicles in much the same way that computer programs are updated and upgraded today. After all, you never know whether you might need a parking assistant when you get older — and what better way to install it than with a download? ■ *Bernhard Gerl*

Wheel-hub motors already enable extremely precise maneuvering in curves. In coming years, they will also make it possible for cars to turn in place.

The Roding Roadster Electric with Siemens wheel-hub motors has an output of 325 hp; the car's lithium-ion battery gives it a range of around 120 km.