Hugging the Road **on Bends**

A new drive system developed by researchers from TUM is set to make electric vehicles a lot more attractive to drivers. The compact and lightweight drivetrain not only optimizes brake energy regeneration, it also increases stability on bends and makes for a more enjoyable ride.

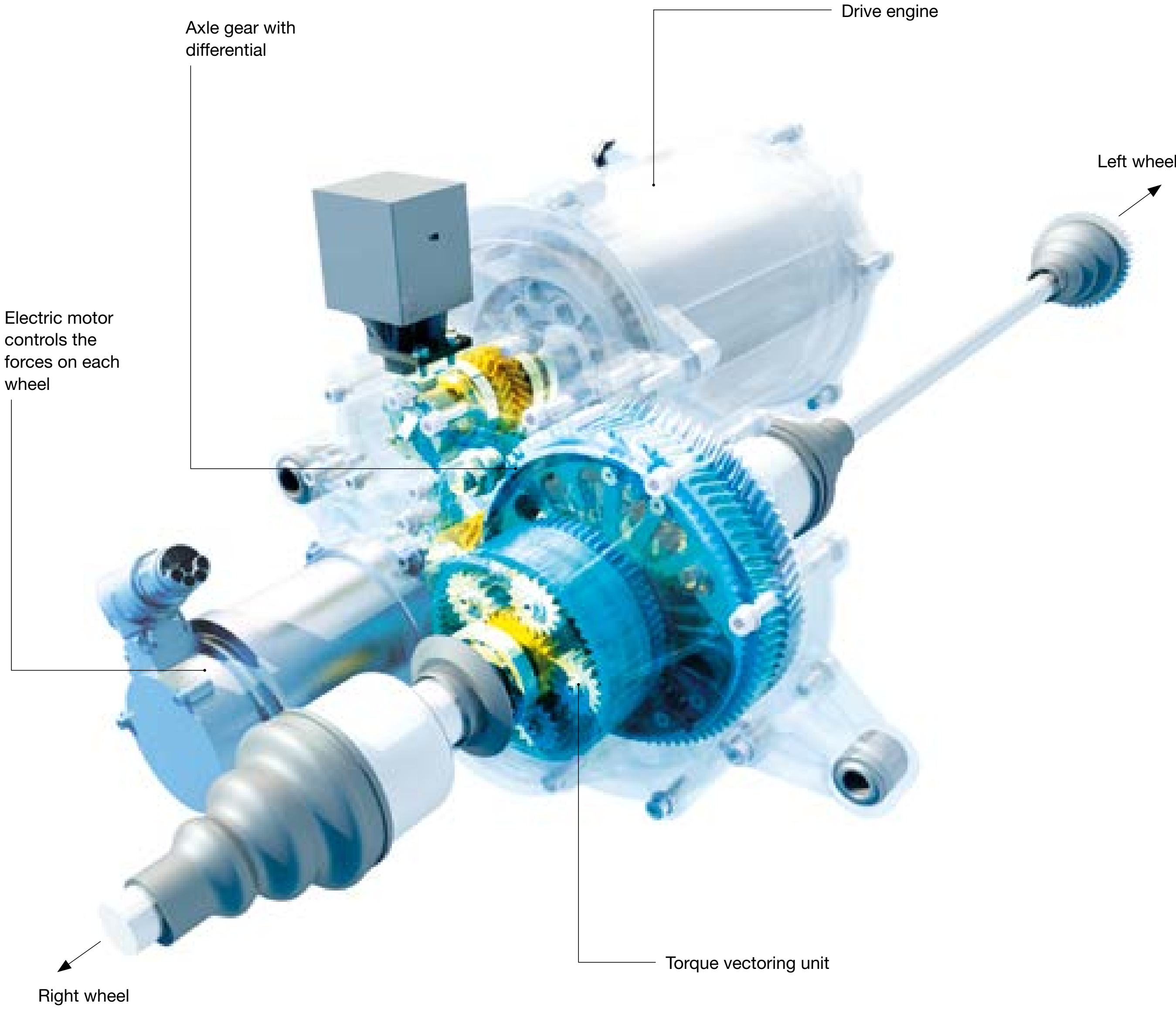
Links

www.fzg.mw.tum.de
www.visiom-automobile.de

Graphics: ediundsepp

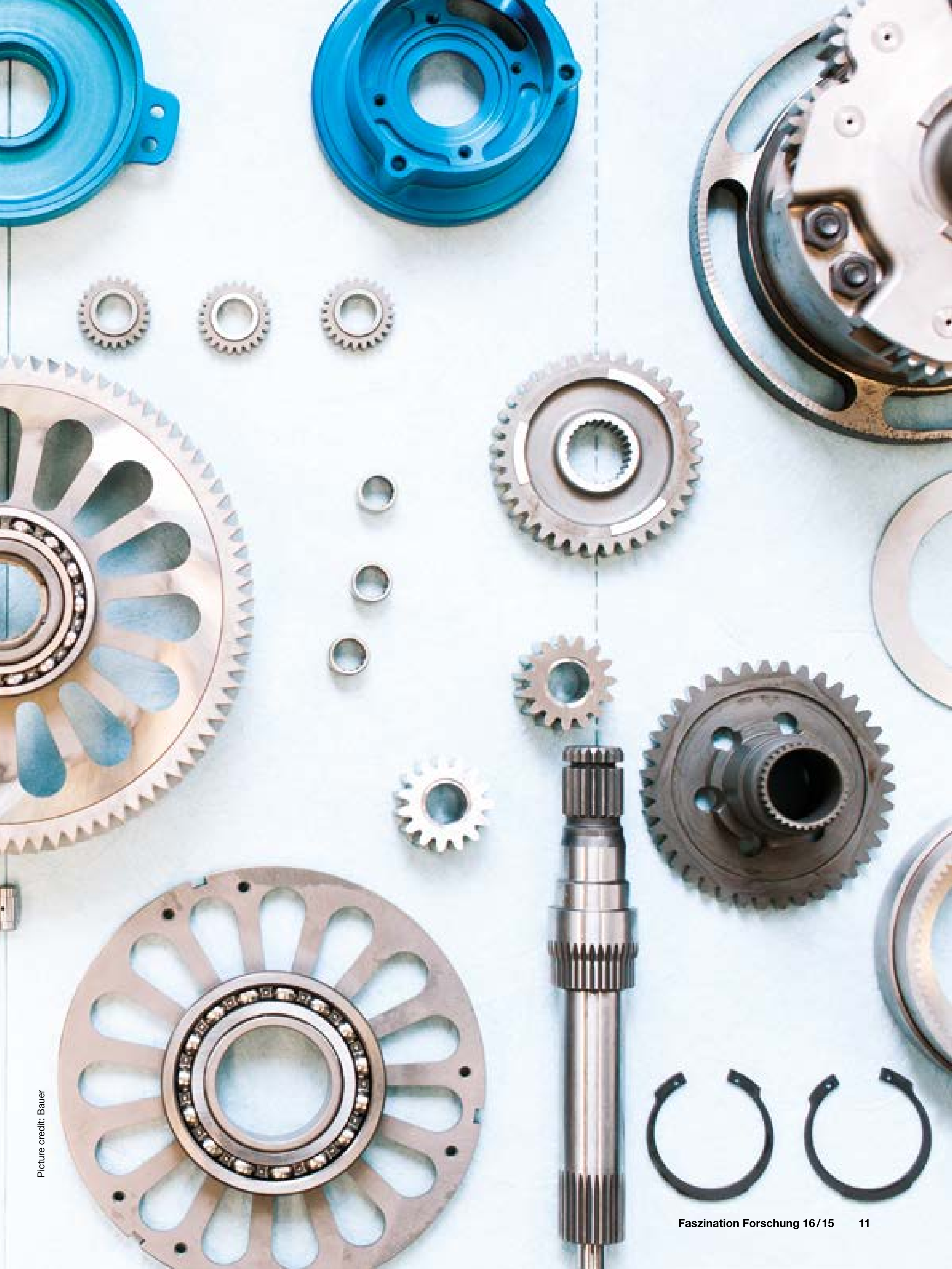
Picture credit: ediundsepp (source: TUM)

Visio.M is the result of a collaborative research effort to develop an electric vehicle that provides safety and comfort combined with a reasonable driving range at an affordable price. The car has a range of around 160 kilometers and space for two people and luggage. With only 15 kilowatts of engine power, the car achieves a top speed of 120 km/h (75 mph). Without its 85 kilogram battery Visio.M. weighs only 450 kilograms. An active torque vectoring differential distributes the force optimally between the two back wheels. This improves stability in curves and helps recover more brake energy.



The Visio.M project

Visio.M is a joint research project funded by the Federal Ministry of Education and Research and involving 14 TUM chairs, the Federal Highway Research Institute, TÜV and a number of partners from industry. The two-and-a-half-year project was completed last year. Its objective was to develop an efficient ultra-compact electric car for two occupants. The brief was that it should not only be safe and lightweight, but also prove that an electric car appealing to the mass market can achieve a lower total cost of ownership than comparable gasoline-powered cars. In October 2014, the Visio.M car was unveiled to the public. The total budget of the project was EUR 10.1 million.



Picture credit: Bauer

“With this small and lightweight torque vectoring drive, we are offering auto manufacturers a powerful component to integrate in electric car designs of the future.”

Karsten Stahl

Ab durch die Kurve

Dank eines neuen Autogetriebes mit Kunststoffgehäuse, das Forscher der TUM entwickelt haben, könnten Elektrofahrzeuge künftig deutlich attraktiver werden. Das kompakte und leichte Getriebe gewinnt nicht nur Bremsenergie optimal zurück, es erhöht auch die Stabilität bei Kurvenfahrten.

Elektrofahrzeuge sind leise und umweltfreundlich, sofern man sie mit regenerativ erzeugtem Strom betankt. Dennoch gibt es hierzulande erst rund 21.000 Stück, da diese Autos meist zu teuer sind und eine geringe Reichweite haben. In dem BMBF-Verbundprojekt Visio.M wurde deshalb in den vergangenen 2,5 Jahren ein Elektrokleinstfahrzeug entwickelt, das leicht und kostengünstig zu produzieren ist und eine attraktive Reichweite hat. An der Entwicklung des Autos war auch die Forschungsstelle für Zahnräder und Getriebebau (FZG) der TUM beteiligt, die für das Visio.M-Fahrzeug ein spezielles Getriebe gebaut hat. Es ist leicht, kompakt und trägt dazu bei, die Energie auch bei Kurvenfahrten optimal zurückzugewinnen – und so insgesamt die Reichweite des Autos zu erhöhen. Wie andere Elektro- oder Hybridfahrzeuge auch gewinnt der Visio.M Energie zurück, wenn er bremst (Rekuperation). Der Motor schaltet dann auf Generatorbetrieb. Die Räder drehen dabei den Motor wie einen Dynamo und werden so abgebremst.

Allerdings ist die Leistungsfähigkeit herkömmlicher Rekuperationssysteme bei Kurvenfahrten begrenzt. Bei normalen Autos wird der äußere Reifen höher belastet, weil das Fahrzeug stärker nach außen drückt. Dieser Reifen kann eine hohe Bremskraft auf die Straße bringen. Der innere Reifen jedoch wird entlastet und kann damit weniger zum Bremsen beitragen. Das an der TUM entwickelte Getriebe hingegen regelt die Kraft, das sogenannte Drehmoment, mit der ein Rad angetrieben oder bei der Rekuperation abgebremst wird, für jedes Antriebsrad individuell. Damit lässt sich bei Kurvenfahrten die Bremskraft eines jeden Rades optimal dosieren.

Zwar gibt es heute bereits derartige Getriebetypen – Experten sprechen von Torque-Vectoring-Getrieben – doch sind diese bisher viel zu groß, zu schwer und zu teuer für Elektroautos. Sie werden allenfalls in einigen wenigen edlen Sportwagen verbaut. Die Leistung der TUM Ingenieure besteht darin, ein besonders kompaktes, leichtes und stabiles Torque-Vectoring-Getriebe mit Kunststoffgehäuse erschaffen zu haben, mit dem die Torque-Vectoring-Technik erstmals auch in Elektroautos eingesetzt werden kann. *Tim Schröder*

Electric vehicles (EV) have a lot going for them. They move silently through busy city streets and don’t emit noxious fumes. There are even some good-looking models on the market now – a far cry from the no-go designs that first appeared ten or twenty years ago. The German federal government is encouraging commercialization of electric cars with measures such as tax incentives. Nevertheless, in 2014, only 21,000 electrically powered vehicles were being driven on German roads. A drop in the ocean compared to the number of conventional cars, which stands at 43 million. It is doubtful that the target of one million electric vehicles in Germany by the year 2020 will be achieved. The high price tag is one factor; another drawback is the limited range of vehicles powered by a battery.

Many engineers around the world are working on a solution to the EV range challenge. But it does not come down to just one technical detail. Rather, the developers will have to optimize the entire car. In November last year, the Visio.M consortium presented a possible answer. A team of developers from industry and various chairs of TUM produced a completely new electric vehicle model. Thanks to its cutting-edge efficiency, its estimated total cost of ownership, including initial investment and operating costs, will be lower than that of a comparable combustion engine car. Decisive for the exceptional energy efficiency of the Visio.M is its light weight. At the same time, the car fulfills all significant requirements of a normal mass market car, from passenger safety to infotainment and navigation assistance to climatization. With its smart design, the Visio.M attracted plenty of media attention when it was unveiled to the public last fall. ▷

Prof. Karsten Stahl heads TUM's Institute of Machine Elements, also called the “Gear Research Centre (FZG)”, today’s leading international research institute for gears and transmissions.

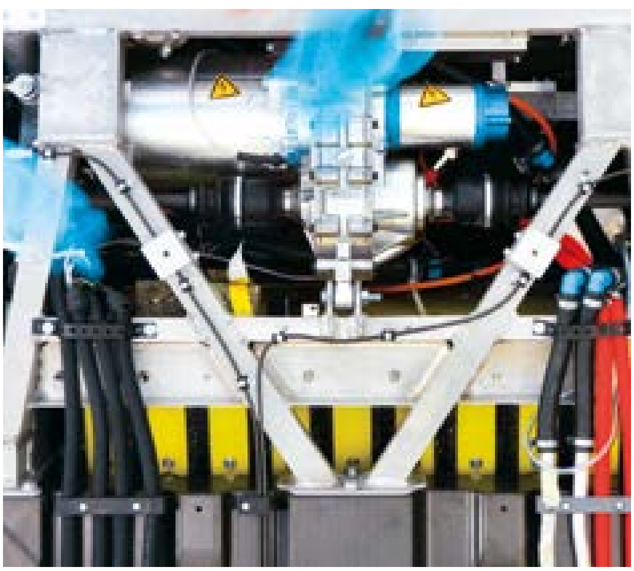
Picture credit: Bauer

“A torque vectoring drive not only offers better recuperation. Car makers can also use it to improve driving stability.” *Philipp Gwinner*

Picture credit: Bauer

TUM engineer Philipp Gwinner and his colleagues first realized a torque vectoring drive that fits into a compact aluminum housing. Then they went one step further and used lightweight glass fiber reinforced plastic to make the housing. Only the shaft bearings are mounted inside an aluminum structure, which is extrusion-coated with the liquid plastic.

Picture credits: Bauer



In the workshop of TUM's Institute of Automotive Technology: The torque vectoring drive installed in the Visio.M electric vehicle (left page). Philipp Gwinner connects one of the sensors (top) to the drive.

Regenerating brake energy

As is customary in electric or hybrid vehicles, the Visio.M recuperates energy when it brakes. When the driver brakes, the motor switches to generator mode. The wheels turn the motor like a dynamo and thus apply braking power. The efficiency of regenerative braking could be increased even further if the braking energy could also be recuperated when driving around bends. However, conventional regeneration systems are not very effective when it comes to handling curves. In standard cars, the left and right wheels of a driving axle exert different pressure on the road surface when going around a corner. There is more load on the outer wheel because the vehicle is veering more to the outside. This wheel can exert a strong braking force on the road. At the same time, there is less pressure on the inner wheel, so it is less effective in braking. Brake energy regeneration has basically not been very effective on bends up to now. In theory, this problem could already have been solved with a torque vectoring drive. Torque vectoring varies the power – or the torque – delivered to each wheel. The same applies to the braking power recuperated from each wheel. This means that just the right amount of braking power gets to each wheel during cornering. Up to now, however, torque vectoring systems were too heavy, too large and indeed too expensive to install in mass-produced electric vehicles. They are currently to be found in only a handful of models, mostly high-end sports cars.

But this is set to change. Researchers at TUM's Gear Research Centre (FZG) have developed a torque vectoring drive system that is sufficiently lightweight and compact for future EVs. Torque vectoring is a particular form of differential gear. A "differential" is located at the center of almost every vehicle's driving axle and is responsible for moving the latter together with the wheels. An ordinary differential gear drives the entire axle and therefore uniformly drives the left and right wheel. Torque vectoring gearboxes do this differently. Depending on the type of bend, more torque can be distributed to the left or right wheel. In conventionally driven axles, that would not be possible. With the new torque vectoring drive, TUM engineer Philipp Gwinner and his colleagues have realized their aim of a compact design. The gearwheels inside the gearbox have been designed and arranged with a view to fitting as much into as small a space as possible. They are closely linked to a small electric motor. This selectively increases the rotation of the left or right axle end, delivers more torque to the left or right, or in the case of cornering, applies the required braking power to individual wheels.

Some experts have long favored wheel hub motors as the future EV drive system of choice. With this concept, each wheel has its own motor that turns or brakes each wheel individually. The effect is therefore similar to that of a torque vectoring drive. With torque vectoring, however, you can get this effect with a single central drive, which is more economical and safer than individual wheel hub motors. A torque vectoring drive offers automakers a range of potential applications – not just better recuperation. "They could also use the drive to improve driving stability," maintains Philipp Gwinner. "If a car becomes unstable when cornering, the individual wheels will be decelerated so that the vehicle restabilizes." If the torque of the wheel at the outside of the bend is increased, ▷

Picture credits: Bauer; left: ediundsepp (source: TUM)

In order to realize a plastic housing for the torque vectoring unit, the TUM engineers had to find a way to reduce the forces of the gear system. They overcame this challenge by designing a double helical gear, in which the axial forces cancel each other out.

it pushes the car into the bend, so to speak. The new drive can also compensate for crosswinds or slippage on wet leaves and ice. “We have designed the torque vectoring drive to be economical, small and light enough for EVs like the Visio.M,” says Prof. Karsten Stahl, Director of the FZG. It took several development stages to achieve the end result. The first task was to arrange and design the gearwheels so that the gear system could fit inside a compact aluminum housing. Stahl and Gwinner then went one step further. They used lightweight glass fiber reinforced plastic to make the housing. Only the shaft bearings are mounted inside an aluminum structure, which is extrusion-coated with the liquid plastic. “With this small and lightweight torque vectoring drive, we are offering auto manufacturers a powerful component to integrate in electric car designs of the future,” proclaims Stahl.

A lightweight gearbox housing made of plastic

Normally, though, plastic housings are scarcely able to withstand the strong forces of a gear system. This was another problem that Gwinner had to overcome. As a rule, the forces of the gearwheels under high load result in severe deformation of the plastic. This happens because the gear teeth are usually arranged at an angle to reduce noise and increase the load-carrying capacity. A normal housing made of plastic is not able to withstand the forces that occur in helical gearing. That is why Philipp Gwinner uses a “double helical gear,” in which the axial forces of each half cancel each other out. This enables the use of plastic material for the automotive gearbox housing.

With a number of benefits incorporated into the new gear design, Stahl is optimistic: “We cannot wait to see how the automobile industry will respond to and eventually use what we have developed.” In any case, the team has proved that it is possible to design a small, lightweight and economical torque vectoring drive. Philipp Gwinner adds: “I firmly believe that this development has huge potential.” The drive is one of the features that make the Visio.M so efficient. The car requires just around a quarter of the energy equivalent consumed by a conventional small car. “It is of course possible to drive a car axle without torque vectoring and to do without the highly complex differential we have used,” admits Gwinner. But that would mean settling for much less functionality, less energy efficiency and less driving pleasure on bends. Above all, this innovative development will make electric vehicles of the future a much more attractive proposition for drivers. *Tim Schröder*