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From the intelligent wheel bearing to the “robot wheel”

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The increasing requirements placed on motor vehicles

Why is the trend heading towards electromobility?

Environmentally-friendly electrical mobility is the expected trend and will become a real alternative to the current state of the art. Innovative technologies, high oil prices and the increasing ecological awareness of many people are reasons, why electromobility is increasingly gaining worldwide acceptance.

The requirements placed on motor vehicles are constantly growing, in terms of fuel consumption, comfort, and safety, as well as in terms of emissions.

The need of vehicles, that excel due to low emissions is increasing, because of the growing awareness of CO_2 emissions, coupled with legal requirements, such as inner city tolls for vehicles with excessive CO_2 emissions and the desire of governments for less dependence on instable oil and gas suppliers – the begin of zero emission.

Along with the environmental situation, the need of more comfort and safety must also be considered as well. Mechanical steering and braking elements are being replaced by mechatronic components thereby leading to higher functionality with increased safety.

When referring to the further developments in safety, the vision of "zero accidents" (autonomous and accident-free driving) has to be mentioned. After slip control braking and driving stability systems, driver assistance systems known as ADAS (Advanced Driver Assistance Systems) are now being created as a further requirement for making this vision a reality.

By-wire technology, amongst others, is one of the prerequisites for the implementation of ADAS. It monitors the current traffic situation and actively supports the driver. By-wire means, that all the driver's important commands are transferred directly via a control signal.

Developing and launching such innovative products on the market is of utmost importance to maintain and increase the competitiveness of manufacturing companies.

The electric drive was transferred to the wheel unit more than one hundred years ago. As early as 1896, Ferdinand Porsche made a patent application for his electric wheel hub motor. Porsche developed the first vehicle equipped with electric motors in the wheel hub for Lohner & Co. coachbuilders in Vienna, that at first did not have the functions, associated with a hybrid vehicle since the wheel hub motor was the only drive in the vehicle.

The first Lohner Porsche with two wheel hub motors on the steered front wheels was presented at the Great Exhibition in Paris in 1900. The electric motors were located on the drive wheel in order to eliminate complex transmissions from the crankshaft to the wheel, that were susceptible to faults. It was possible to eliminate the transmission and drive shaft since the wheel rotated as the rotor of the direct current motor around the stator, that was fixed to the wheel suspension. The drive therefore operated without mechanical friction losses with an impressive efficiency of 83 percent. The output of each electric motor was a maximum of 7 horsepower, whereby the normal output was 2.5 horsepower and 120 rpm. However, at this time up to now, the size of the battery was a decisive weakness. The 44-cell lead acid battery with 300 ampere hours and 80 volts had a range of 50 kilometers. The battery weighed 410 kilograms with a vehicle weight of nearly one ton.

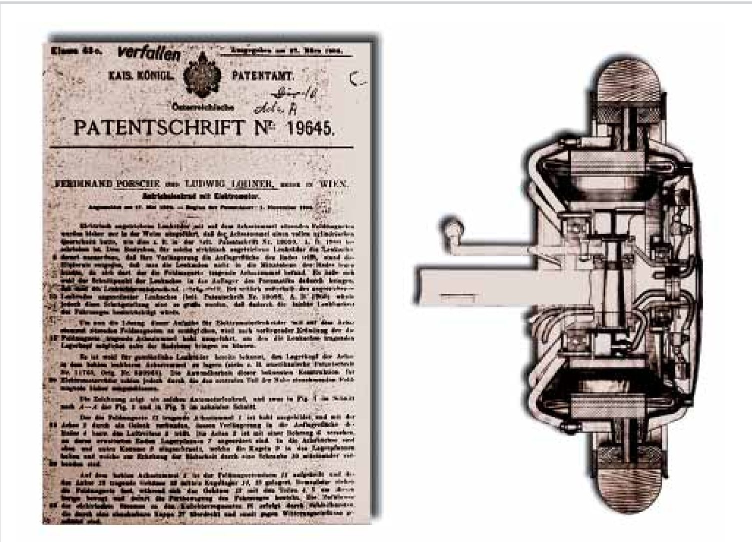

Figure 1 Patent specification and design of F. Porsche's wheel hub motor [1]

Figure 2 The first electric vehicle, built in 1835 [1]

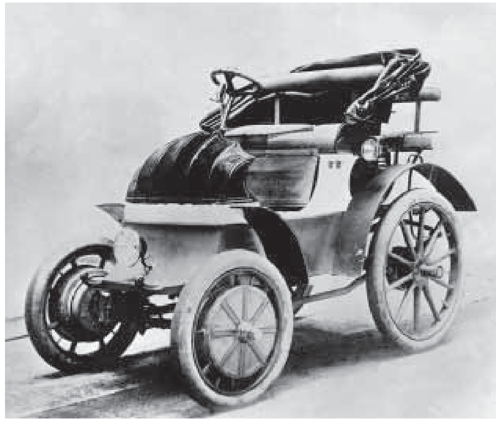

Figure 3 Lohner-Porsche at the Great Exhibition in Paris in 1900 [1]

The racing version of the Lohner-Porsche developed during the same year was equipped with four-wheel drive and the batteries for the four power generators alone weighed 1800 kg. Despite its high weight, the racing car still managed a speed of 60 kilometers per hour.

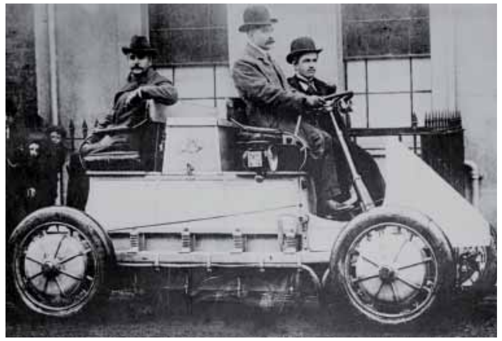

Figure 4 Lohner-Porsche with four wheel hub motors in 1900 [1]

In order to compensate for the lack of range, offered by a vehicle only powered by electricity, Porsche developed the "Semper Vivus" in the same year, a vehicle with a petrol-electric drive system (mixte - the term range extender is used to describe this system today), which was the precursor to all automobiles today with hybrid drives. The internal combustion engine supplied electricity for both electric motors via a generator. It was also possible to activate the gasoline engine after starting the vehicle so that the electric motor functioned as a generator to charge the battery. Both motors could also be used together if necessary.

Modern hybrid electric vehicles (HEV) also save fuel by storing kinetic energy released during braking and delivering it to the electric motor during acceleration to support the internal combustion engine. The latter is switched off when the vehicle is stationary or during slow travel. However, if full power is required again, both the internal combus-

Figure 5 Lohner-Porsche Mixte with gasoline and electric drive (1901) [1]

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tion engine and the electric motor power the vehicle. The advantages of splitting the power in this way are, that a smaller internal combustion engine is required and the excellent torque characteristics of the electric motor improve the acceleration.

Most HEV have a parallel configuration, i.e. the vehicle has an electric motor and a large battery, as well as the mechanical drive train, that runs from the internal combustion engine to the wheels.

In the case of the series configuration, on the other hand, the wheels are driven by one or more electric motors and instead of the mechanical connection to the wheels, the internal combustion engine powers a generator, that generates electricity for these motors. This type of hybrid vehicle is also known as a plug-in HEV.

While the first hybrid vehicles used bulky lead acid batteries, the batteries in today's vehicles are considerably smaller. Toyota and Honda, who have already made very significant progress in marketing efficient hybrid vehicles with reduced fuel consumption, use lighter and more environmentally-friendly nickel-metal hydride batteries (NiMH) instead of lead batteries. The long operating life of these batteries is an additional advantage. However, the disadvantage is the somewhat weak efficiency when converting energy and the increase in temperature of the batteries, associated with this when charging and discharging. The best charging efficiency is available at 50 to 70 % charge. A larger mass is required, however, for operation with partial charge.

Parallels to developments in robotics

If one raises the question as to which parallel technologies have undergone similar development and in which direction the car of the future is heading, one observes that the origins of the mechatronic approach and the trend towards autonomy originate in robotics.

In the past, however, robots have always been one step ahead of the automobile in this respect and the automobile has made great progress in the meantime. A continuous convergence has been taking place during the last few decades in particular, so that the complete fusion of robots and automobiles can already be seen in the same applications and similar technologies and is inevitable in the future. Nowadays it is the vision, that fully integrates the technologies of the automobile of the future with the modernity of the robot.

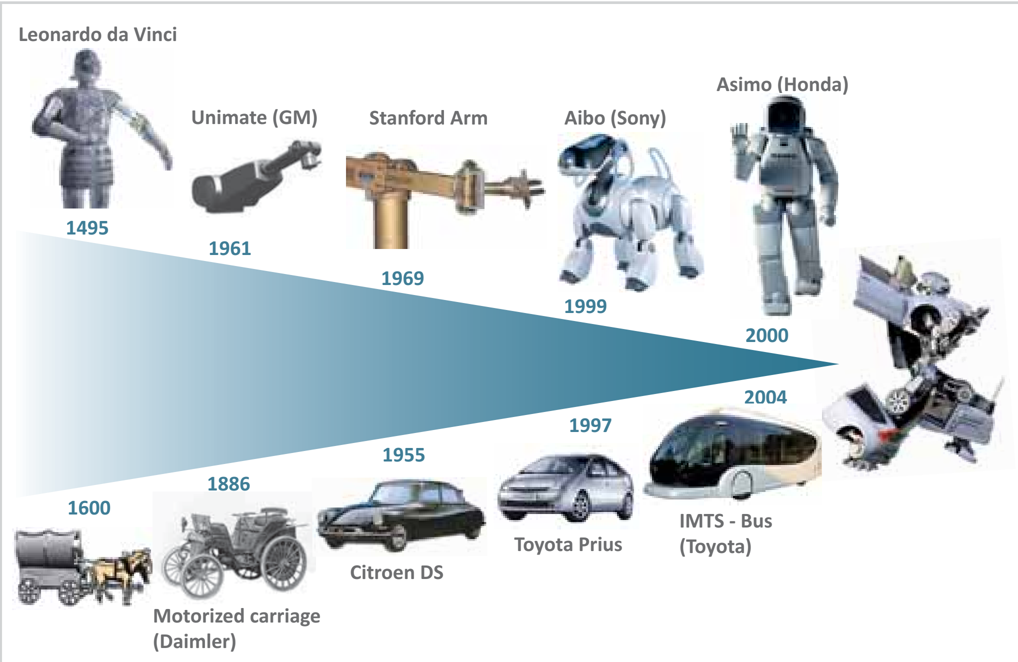

Figure 6 Developments in robotics and the automobile sector

If the automobile and robot are reduced to their core components, it is possible to recognize the basic similarity of the classic machines present: Power train, control system, body and chassis. The drive of an articulated axle in a robot is therefore comparable in principle with the drive of a wheel in a vehicle. It therefore stands to reason that spatial and functional units are integrated in a similar manner as is the case with robots. This combination is referred to as "robot wheel" below.

An outlook for the automobile of the future

The first promising step towards the robot wheel is the development of the intelligent wheel bearing by the Schaeffler Group. This involves, for example, building on the modular concept in which design elements of the wheel bearings' surroundings are linked to the bearing. Combining mechanical and electronic components, such as sensors for measuring wheel and braking force, is an additional development trend.

The sensors integrated into the wheel bearing unit form the basis for the development. These sensors measure the distribution of stresses in the wheel bearings during various driving conditions such as acceleration or braking. The common permanent wheel force measurement means, that all forces and moments in the wheel can be seen at any time. This means, that such wheel bearings form the basis for more extensive assistance systems beyond ABS or ESP, with which the longitudinal and transverse dynamics of the vehicle can be controlled for the safety of the passengers.

Figure 7 The intelligent Schaeffler wheel module

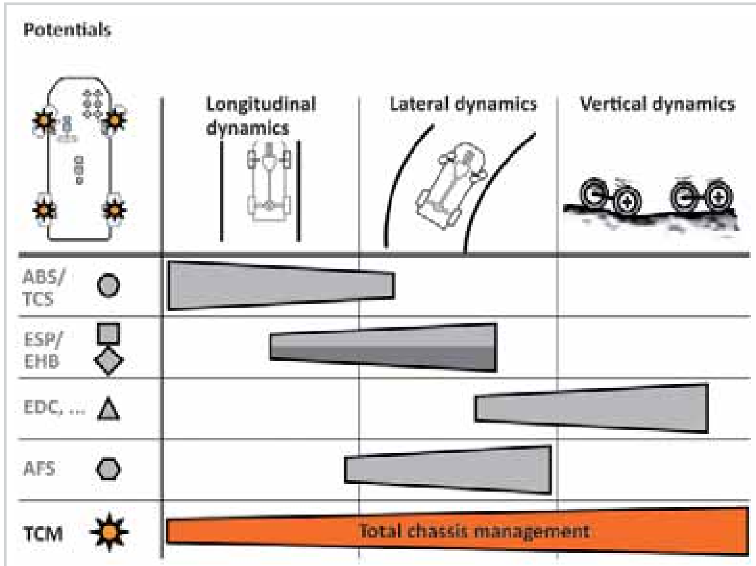

Figure 8 Longitudinal and transverse dynamics of the vehicle for the safety of the passengers

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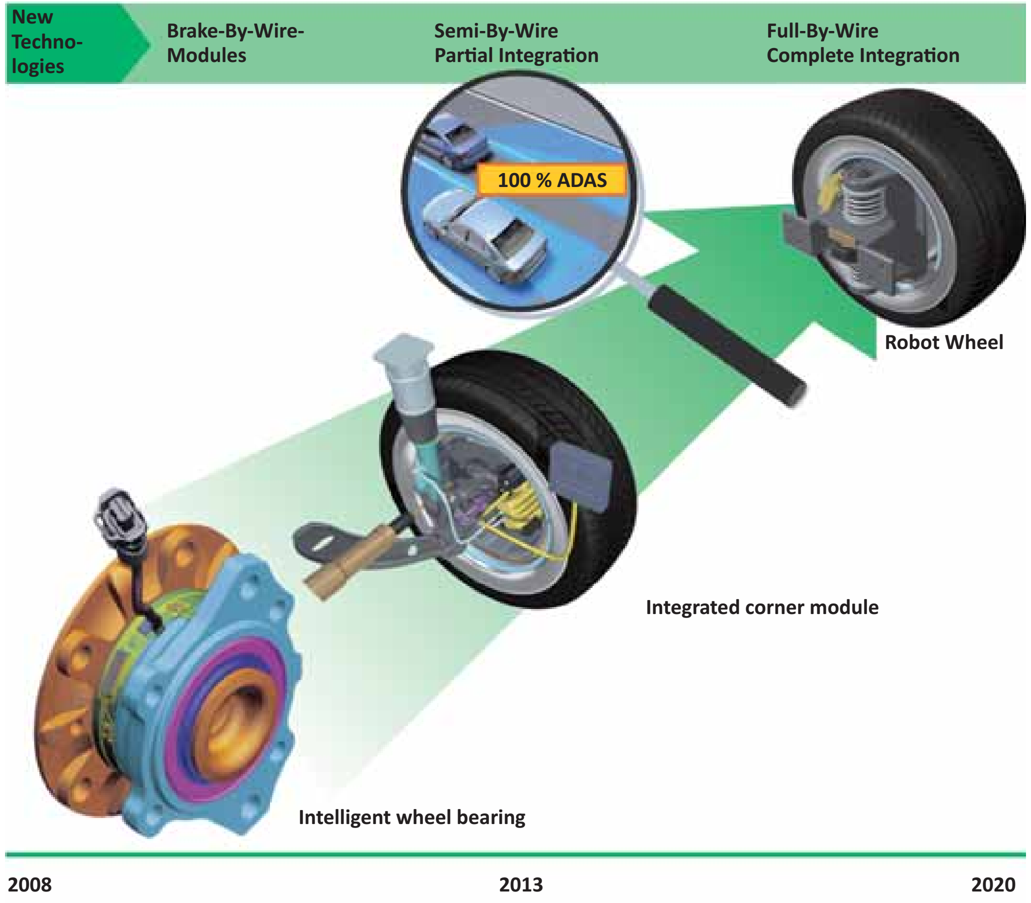

Figure 9 From the intelligent wheel bearing to the robot wheel

Alongside the wheel hub motor, steering and damping will be integrated in the center point of the wheel. At first, the wheel will contain mechatronic components for damping and electric brakes with the relevant sensor signal processing and electronic components, such as tire pressure monitoring, (tire guard) as well as subsystems of the chassis control unit (integrated "corner module"). A final step will involve integrating electric steering into the corner module. The implementation of the robot wheel will enable each of the four wheels to be driven, braked, steered and damped individually and actively via "by wire" commands.

One can imagine this system to be similar to a skateboard in that the power generation system and drive are mounted in a "platform". If one considers future energy storage systems or fuel cell technologies, one can expect that these concepts will soon become reality. The usage level of electronics and the intelligent linking and merger of components also therefore increases the level of vehicle autonomy.

Figure 10 "Skateboard principle" with chassis and body [2]

Literature

[1] Historical archive of Porsche AG (www)

[2] MIT study about the Wheel Robot, http://www.carbodydesign.com/detail.php?id=742, 2005