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Components for Powertrain Electrification

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Introduction

The current development of vehicle powertrains is strongly driven by the need for improved efficiency and the reduction of harmful emissions (an industry increasingly underlined by legal regulations). This development is hand in hand with the increase of powertrain electrification.

A combustion engine transforms the chemical energy of the fuel into mechanical energy. This is used for accelerating or maintaining the speed of the vehicle, i.e. for the increase or the maintenance of kinetic energy.

During acceleration or braking phases, this energy is mainly converted to friction and through this into heat. This heat energy is transmitted to the environment and therefore no longer available for powering the vehicle.

An electric drive can be used either as a motor or as a generator, if designed appropriately. The combination of the combustion engine with an electric drive offers the possibility of re-using the energy; which, has already been used to increase the kinetic energy during slow down of the vehicle, at least for a partial regain of it (recuperation).

This energy can be used for the next acceleration phase, either in combination with the combustion engine or with the electric motor.

The combination also offers a clear gain of driving dynamic. Depending on the type of hybrid system both combustion engine and electric motor can be used simultaneously for the acceleration of the vehicle (boost), without increase of consumption or harmful emissions.

A further step is the temporary use of just the electric motor. In this case the combustion engine can be diminished in size and serves only as a backup solution (Range Extender) or is cancelled completely.

Market overview and requirements

The development in the field of powertrain electrification regarding technological requirements is very diverse, ranging from simple stop-start systems (sometimes called micro hybrid), to full and plug-in hybrids, up to pure electric vehicles (Figures 1-3).

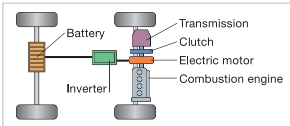

Figure 1 Principle mild hybrid

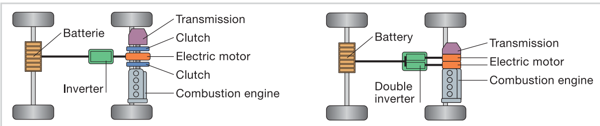

Figure 2 Principle Full hybrid/Plug-in hybrid (Parallel hybrid left/Powersplit right)

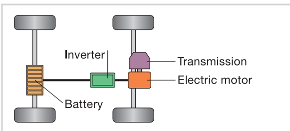

Figure 3 Principle electric vehicle

This variety mirrors the diversity of applications for vehicles already on the market and currently in development with the OEMs.

Figure 4 shows the different approaches of the various OEMs (color of circles symbolizes different vehicle manufacturers) regarding capacity, functional range (HEV, EV etc.) and volumes (quantity symbolized by size of circles).

Continental is the first supplier, independent of car manufacturers, in series production with a complete hybrid system (energy storage, e-machine and power electronic) since 2003. From which, we have gained extensive experience in development and series production. For the development of adequate components for all, or at least a good part of these programs (Figure 2), considerable resources are required for this demanding technology. There is a conflict of aims concerning the economic application of this technology and the suppliers face great challenges.

To solve this conflict Continental has developed a modular component concept which has been in production for several OEMs since September 2008.

Product portfolio – Modular concept

On the following pages you will find an overview of the product portfolio (Figure 5). Using the example of the battery and the power electronics, the modular concept will be explained.

The portfolio covers all core components of an electric drive system for hybrid and electric vehicles. The components are, partly, independent of the architecture and functionality employed in the powertrain (see Figures 1-3).

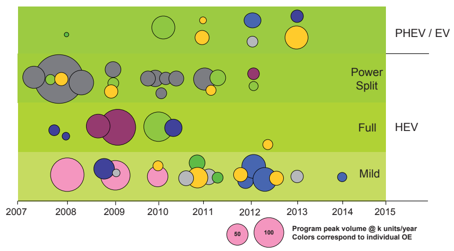

Figure 4 Technology variety by means of a selection of OEM programs

Figure 5 Overview product portfolio

Power Net System (PNS)

The increasing electrification of ancillary units aggregates the increase of consumer-comfort functions and the adoption of the stop-start function. This interrupts the energy supply through the generator during the stop phase and requires solutions for the coverage of the power supply in the 14 V board net.

The PNS provides, through its own energy storage, usually DLC (double layer capacitor) in connection with a DC/DC converter, the potential for a temporary energy supply during consumption peaks or it can take over the complete vehicle power net supply during the stop phase.

The required energy is usually stored during deceleration phases (coasting mode or braking) in the DLCs and offers an additional potential for reduction of consumption.

Energy storage – Li-ion batteries

The capacity of a hybrid or electric drive is mainly defined by the capacity of the energy storage. Therefore, it plays an important role in the fuel reduction potential in hybrid applications, as well as for the range limit of electric vehicles. At the same time the currently requested lifetime of such an energy storage system is 10 to 15 years and 160 000 to 240 000 km; and therefore, is as high as a vehicles lifetime.

For energy storage in hybrid applications (except micro hybrids) various technologies are used today, mainly double layer capacitors (DLC) in conjunction with lead acid batteries, NiMH (nickel metal hydride) batteries and Li-ion (lithium ion) batteries.

NiMH batteries have already been established in the first hybrid vehicles. For the new generation a wide application of Li-ion batteries is emerging.

They show a further increased power and energy density taking into account the required charge and discharge cycles (Figure 6).

Due to the potential of Li-ion energy storage systems and their emerging application in hybrid and electric vehicles, Continental focuses on the development of these systems.

Overview of the modular battery concept

Apart from the cells, the core components are the cell supervising components (CSC), the main contactors, the switches and the battery management (BMC).

The idea behind the modular concept is the use of as many generic parts as possible, independent from the application of the battery. Within the battery these are mainly safety components and sensors, battery management and the electronics for cell supervising (Figure 7).

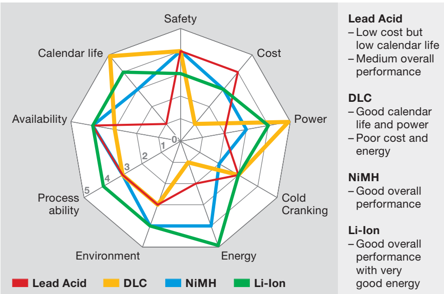

Figure 6 Comparison of different battery systems for automotive application

The application of the batteries, e.g. in a mild hybrid or electric vehicle, determines the choice of the cells.

The cells are the actual energy storage components. To guarantee a safe and reliable application in automobiles a multitude of parameters, e.g. state of charge (SOC), state of health (SOH), temperature, charge-discharge currents and voltage must be monitored and controlled.

The wording Li-ion is a generic term for various combinations of materials. Currently, cells mainly use lithium cobalt. Advancements are moving towards cells with new cathode materials such as lithium cobalt nickel manganese oxide or lithium iron phosphate. All these combinations have advantages, as well as, disadvantages regarding capacity or energy density, and safety. So, there is also the chance for using the same type of cell, as long as, the application purpose defines the same requirements (e.g. a cell for defined power categories in the mild hybrid range).

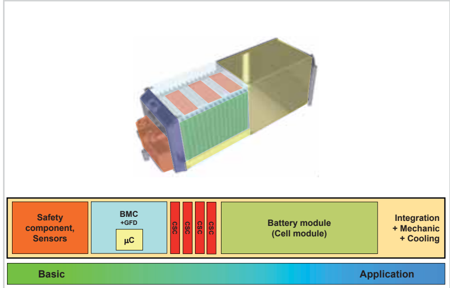

Figure 7 Modular battery concept (lower progress bar color green = generic parts; basic-blue = specific to the application)

Current products

Figure 8 shows a selection of batteries currently in development or series production.

The 1st and 2nd platform (HEV) are power-optimized batteries for the application in hybrid vehicles. The 3rd and 4th platform include energy-optimized batteries for the utilization in plug-in hybrids and electric vehicles.

Power electronic

The power electronic controls the energy flow (inverter) from the battery to the electric motor (e.g. boosting, electrical driving), as well as, the reverse direction from the motor to the battery (e.g. recuperation). In addition, it provides an op-

Li-Ion Energy Pack	ELF1-1	ELF2-20	ELA2-40	ELF2-60	ELF2-120	ELF3-105	ELF4-55	ELF4-60
Project Status	Production	A-Sample	B-Sample	B-Sample	B-Sample	A-Sample	A-Sample	B-Sample
Max. Discharge Power @ 10s / 25°C	19 kW	20 kW	40 kW	60 kW	120 kW	105 kW	55 kW	60 kW
Nominal Voltage	122 V	126 V	302 V	350 V	774 V	360 V	324	346
Capacity	6 Ah	5,5 Ah	5,5 Ah	5,5 Ah	5,5 Ah	40 Ah	45 Ah	50 Ah
Volume ca.	13 l	12 l	45 l	78 l	150 l	120 l	130 l	140 l
Weight ca.	26 kg	24 kg	45 kg	70 kg	145 kg	180 kg	160 kg	175 kg
Nominal Energy (typically useable)	800 Wh (250Wh)	730 Wh (290 Wh)	1.700 Wh (680 Wh)	1.830 Wh (730 Wh)	3.660 Wh (1460 Wh)	14.400 Wh (10.800 Wh)	14000 Wh	17300 Wh

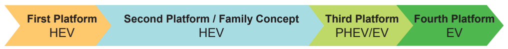

Figure 8 Selection of current energy storage products

tional connection with a DCDC converter between conventional board net (14 V) and the electric drive battery. This makes it the heart of the electric drive.

Modular concept power electronic

The design of the power electronics is similar to the battery concept. So that as many applications as possible can be realized with as many generic parts as possible. Optionally the DCDC converter can be fitted into the inverter housing or in a separate housing (Figure 9 in green).

The scalability continues in the power modules of the inverter to cover various performance classes (Figure 9 in orange) and still use, as far as possible, the same cooling unit, housing etc.

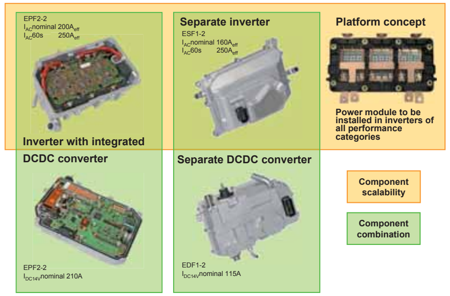

Figure 9 Modular concept power electronic

Performance classes

With the performance classes available today all application-ranges from mild hybrid up to electric vehicles are covered.

Inverter	ESF1-x	EPF2-2	EPF2-3	EPF2-4
Project Status	SOP	B-Sample	C-Sample	C-Sample
$Current_{AC}$ continuous	160 - 330A_{rms}	175A_{rms}	235A_{rms}	245A_{rms}
$Current_{AC}$ peak @ 0,5s	210 - 420A_{rms}	265A_{rms}	355A_{rms}	440A_{rms}
DCDC converter	EDF1-1	One of three different DCDC classes integrated		
Current continuous	150A_{rms}	150A_{rms}	180A_{rms}	210A_{rms}
Current DC peak	180A_{rms}	180A_{rms}	210A_{rms}	240A_{rms}
Approx. Volume / Weight	7,4l / 9kg	5 - 5,5l / 7,5kg		6l / 11kg
Cooling Type	Fluid	Fluid	Fluid	Fluid

Separate inverter and converter — Integrated inverter & converter

Figure 10 Performance classes – inverter/DCDC converter

Electric motors

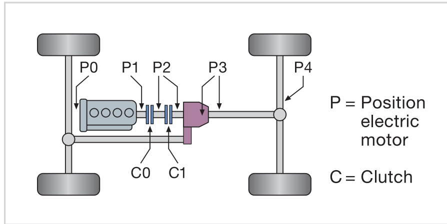

Figure 11 Possible installation positions of electric motors

Depending on strategy and use of a vehicle, different numbers and technologies of electric motors are employed. The aim is to use the optimal technology for the respective purpose. This can be determined by the costs of the system, the available installation space, the required features, as well as, the degree of efficiency.

Figure 11 shows possible installation positions of electric motors in a powertrain. For each of these positions different varieties are possible, so that the high number of possibilities is evident.

Currently, mainly three types of electric motors are in wide use. These are the asynchronous motor (ASM), the permanently excited synchronous machine (PSM) and externally excited synchronous machine (SM).

Overview motors

The asynchronous motor is very robust and cost efficient, but its efficiency is sub-optimal. Due to this, it is preferably used in cost-value optimized mild hybrid systems in the side-mounted version (Figure 12, column 1 and 2 – Type IM).

The PSM is, due to its comparatively short axial length, preferably used for the direct integration into the transmission bell housing. It offers at a certain point a high efficiency factor and is often implemented for mild and full hybrids.

In a pure electric drive, in contrast, a high efficiency factor over a wide range of torque and motor speed is needed, since this assures an optimal utilization of the battery. Here preferably the SM in the form of an axle drive system (Figure 12, column 3 type SM) comes into use.

In cooperation with ZF

Electric Machine types	IM	IM	SM	PSM	PSM	PSM
Project Status	C-Sample	B-Sample	B-Sample	C-Sample	SOP	B-Sample
Nominal DC-Voltage	115 V	150 V	300 V	230 V	120 V	310 V
Maximum Speed	17.000 rpm	16.000 rpm	12.000 rpm	14.000 rpm	6.000 rpm	7.500 rpm
Maximum Torque	66 Nm	50 Nm	225 Nm	290 Nm	160 Nm	250 Nm
Continuous Power	5 kW	5 kW	35 kW	74 kW	8 kW	35 kW
Peak Power	17 kW	10 kW	70 kW	105 kW	15 kW	50 kW
Cooling Type	Fluid	Fluid	Fluid	Fluid	Fluid	Fluid

Side-mounted Starter Generator — Axle drives — In line

Figure 12 Selection of current electric motors

Chances and risks (OEM/supplier)

The strongly growing market of powertrain electrification is not limited to vehicles. Plug-in hybrids and electric vehicles can be charged at the power socket. The conjunction, to the common electricity network (vehicle to power grid), creates new tasks and challenges regarding technology, as well as, for future business models.

The potentials in battery development show that the subject powertrain electrification is yet at the very beginning. This is shown by certain facts. Today's Li-ion batteries reach an energy density of 120 - 150 Wh/kg. Theoretically 6000 Wh/kg (lithium fluoric) are possible and practically readings of up to 2000 Wh/kg are expected.

Due to the considerable improved efficiency grade of electric drives and the possibilities for energy recuperation; there is a wide-spread assumption that an energy density of approx. 500 Wh/kg ranges comparable to vehicles with combustion engines, can be realized.

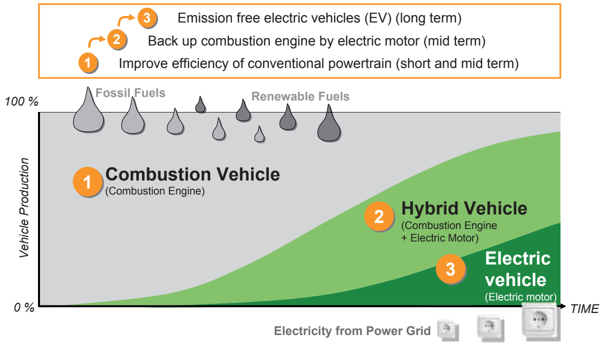

Figure 13 Growing significance for electrification

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