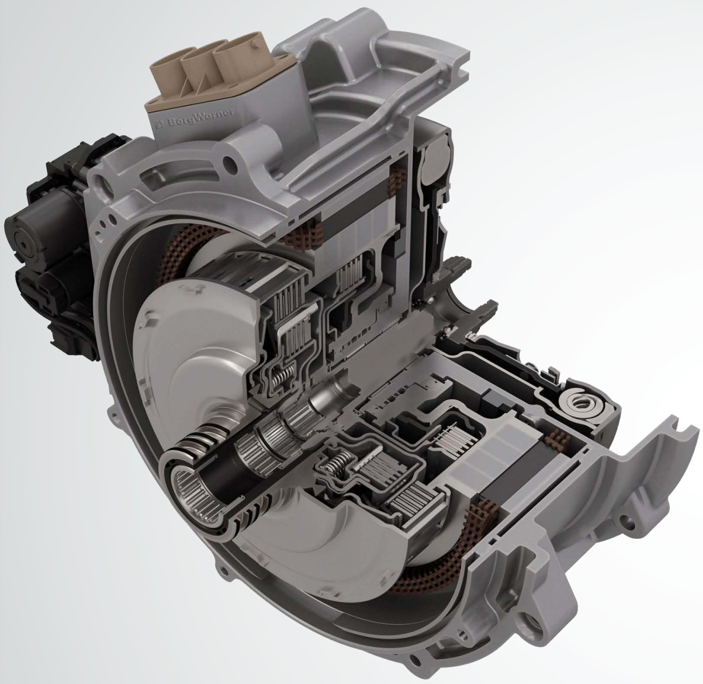

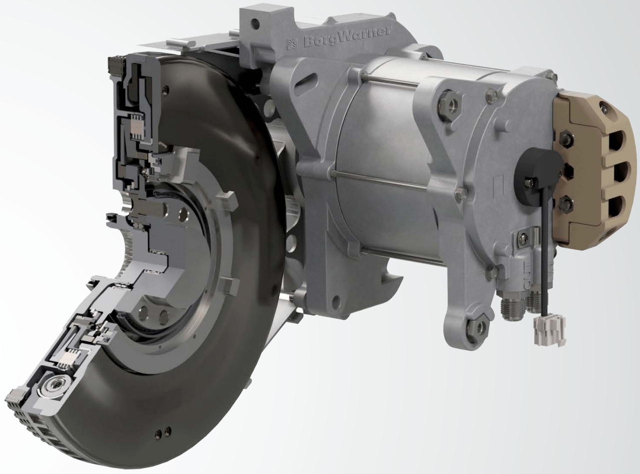

Hybrid

BorgWarner P2 Hybrid Modules

Multiple Design Combinations for Optimized Customer Solutions

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BorgWarner P2 Hybrid Modules Multiple Design Combinations for Optimized Customer Solutions

BorgWarner's popular P2 hybrid architecture offers a wide range of functions and design options. It is extremely easy to integrate into a drivetrain and the many possible variations assure that the BorgWarner modules can be optimally adapted to specific customer requirements.

Eckart Gold, Engineering Director, BorgWarner Transmission Systems China.

Introduction

Much of the innovation in the automotive industry today is being driven by stricter emission standards, increasing urbanization and a greater focus on sustainability. As a result, the predominant drivetrain architectures will be the so-called P1 and P2 configurations (Fig. 1). Unlike the P1 design, the P2 solution enables pure electric driving by using a disconnect clutch to disengage the combustion engine. Furthermore, the P2 module offers a wide range of functionality and can easily be integrated into the drivetrain, which makes it the solution of choice for hybrid vehicles.

On-axis and off-axis modules offer unique solutions

The electric motor in a P2 configuration can be positioned either on-axis or off-axis. With the on-axis design, the motor is integrated directly into the drive shaft. In the off-axis version, the motor is positioned separately, with torque and speed being conveyed by a transmission device.

The choice between these two configurations and their optimum positioning depends on a wide range of criteria, with a dominant influencing factor “installation space”. Drivetrains with a longitudinally mounted engine typically have more space available, therefore an on-axis arrangement is preferable. Compared to the off-axis version, the electric motor of the on-axis module is heavier, however does not require any additional torque transmitting components. Since it is positioned directly on the driving axle, it also doesn't need additional installation space adjacent to the transmission.

In contrast, off-axis configurations are often found in applications with a transversely mounted engine, as additional axial installation space between combustion engine and transmission is often hard to find.

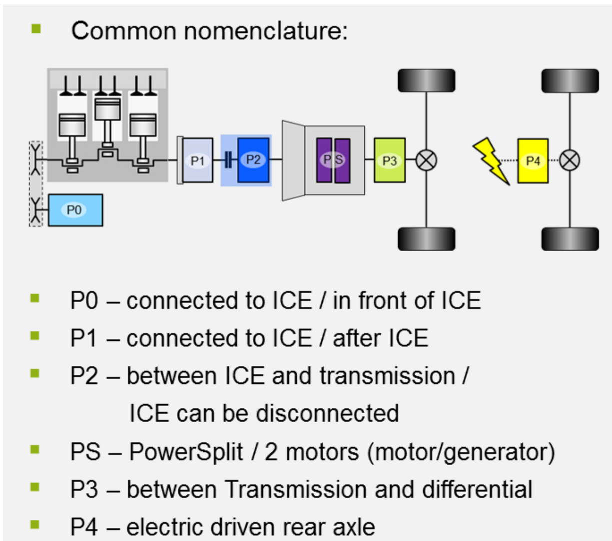


Figure 1. The P2 configuration enables pure electric driving through the use of a disconnect clutch.

Flexible clutch concepts to satisfy customer requirements

P2 hybrid modules usually include a simple disconnect clutch, allowing all kinds of transmission options. A wet friction clutch delivers maximum functionality and durability at compact dimensions. In on-axis configurations, the rotor unit of the electric motor and the clutch housing can be combined as one component by integrating the disconnect clutch into the electric motor. This combination also allows simultaneous cooling of clutch and rotor with the same coolant.

For applications requiring an alternative to the conventional concept, the triple clutch is an effective solution (Fig. 2). It is especially suitable for dual clutch hybrid transmissions since, in addition to the disconnect clutch, the dual clutch is integrated into the electric motor. As a result, the overall length of the hybridized dual clutch transmission becomes extremely competitive.

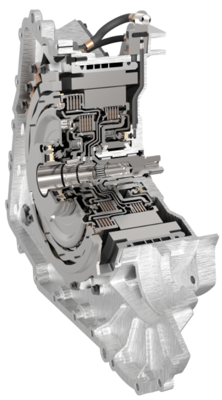


Figure 2. While the triple clutch shown here optimizes the length of the dual clutch hybrid transmission, the conventional P2 module is an effective solution for all types of transmission.

Using a one-way clutch (OWC) instead of a wet disconnect clutch will help to further reduce the installation space required as well as the complexity and cost of the system while increasing the efficiency. However, when used in conjunction with automatic or continuously variable transmissions, the engine's braking effect will be lost. This problem can easily be solved by using a dual clutch transmission (DCT), with an OWC and electric motor positioned in connection with one partial transmission only (Fig. 3).

To further increase the efficiency of wet clutches, a locking mechanism can be integrated which allows the clutch to lock while retaining its maximum ability to transmit torque although the holding pressure is reduced to a minimum (Fig. 4).

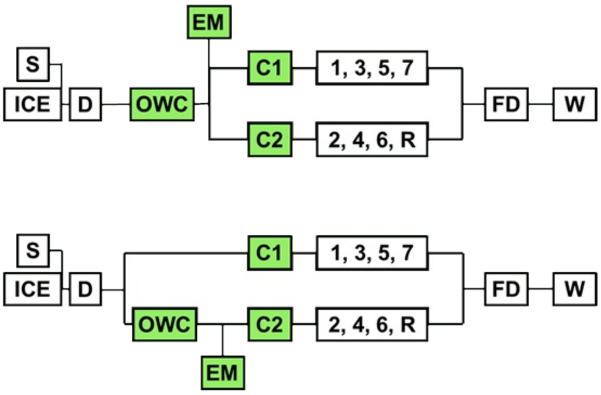
Defining the best possible electric motor design

Criteria such as Noise, Vibration, Harshness (NVH) behavior, installation space requirements and design of the stator and rotor, as well as motor efficiency are the most important aspects for selecting the optimum electric motor.

One benefit of an off-axis P2 configuration is that – with a typical gear ratio of about 3 – the electric motor can be operated at higher speeds which leads to improved efficiency, while still providing sufficient power for the drivetrain.

An electric motor with a larger diameter and operated at lower speeds on the other hand generates more torque, making it the optimum solution for an on-axis configuration.

Energy efficiency, reduced emissions and cost savings are important requirements that can be fulfilled by selecting the optimum operating voltage. The various advantages and disadvantages of different high-and low-voltage systems need to be taken into consideration (Fig. 5). Low-voltage systems, for example, are limited to an output of less than 25 kW because they usually operate at a direct current of less than 60V, provide limited performance but high cost-effectiveness. The output provided by high-vol-



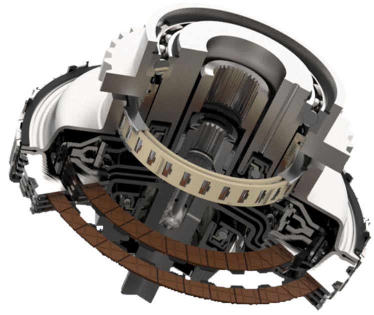


Figure 3. The OWC reduces the required installation space, complexity and cost, while increasing system efficiency.

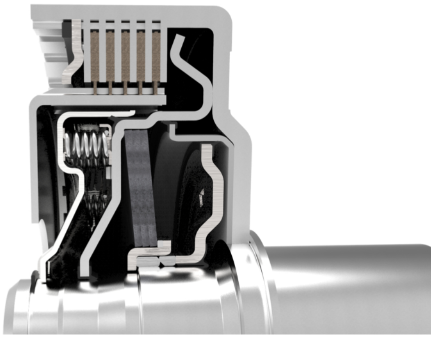
tage systems, on the other hand, is above 100 kW which enables pure electric driving with considerable fuel and CO_2 savings. But due to the higher voltage safety requirements are higher which typically leads to less cost-effective systems.

Temperatures and operating conditions are important factors defining the design and method of a cooling system for the electric motor. Maximal efficiency for maintaining a certain average temperature can be achieved by using the oil cooling method which provides an ideal heat transfer due to the direct contact between coolant and principal thermal components.
Another solution is the use of a water and ethylene glycol mixture. A so-called cooling jacket dissipates the heat from the electric motor via the stator's external diameter. While the average efficiency is limited because of the spatial separation of coolant and heat source the effect on temporary temperature peaks can be interesting due to the bigger delta temperature usable with a water-cooling jacket.

Therefore, the best solution is a combined approach. In this configuration, the water and ethylene glycol mixture is flowing around the stator at a reduced inlet temperature of 65°C (instead of a typical 90°C transmission coolant temperature), while internally injected oil dissipates the heat from within the rotor. Since the best solution is usually creating the highest cost the required cooling capacity needs to be analyzed during the concept phase. In some case the benefits of an additional cooling jacket do not justify the on cost and a system with internal oil cooling only is the better choice.

The winding and its effects on the NVH behavior also have an influence on the design of the electric motor. BorgWarner distinguishes between concentrated and distributed stator windings and between the use of round or square wire. The machine's NVH behavior can be improved by using distributed windings, achieving low torque ripple (less than 5% in the coaxial configuration) and a low cogging torque. The distributed stator windings further contribute to an optimized NVH behavior across the entire system by considerably reducing motor pulsations. The use of concentrated stator winding in a comparable electric motor results in a torque ripple that is up to 20% higher.

In order to maximize the current density, distributed windings use a conductor with a square cross-section. The enlarged contact surface al-



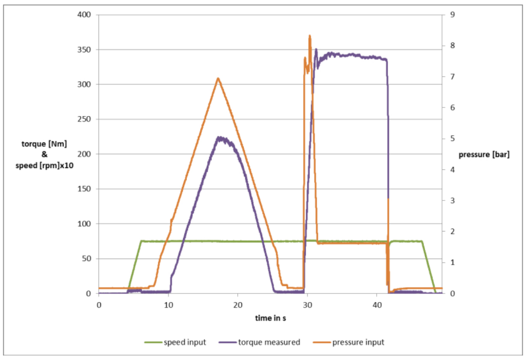


Figure 4. CO_2 emission from hybrid vehicles is reduced by 1.5g CO_2/km when using the locking mechanism in conjunction with a disconnect clutch.

so optimizes the heat transfer between stator lamination and conductor. Moreover, this solution contributes to efficiency because the slot fill ratio is increased in comparison with round wires. Electric motors with square wires can provide considerably higher continuous power than motors with round wires according to analyses and tests conducted under identical basic conditions.

Regarding rotor design, BorgWarner makes a difference between three-phase induction machines and permanent magnets. These also differ regarding the use of either interior permanent magnets (IPM) or surface-mounted permanent magnets (SPM). IPM rotors can be used for all stator designs to increase overall performance and efficiency. As opposed to three-phase induction machines, they maintain the magnetic field in the rotor without the need for external excitation. Peak outputs of a three-phase induction machine are similar to those of the permanent magnet version at lower cost because of short-term high currents, but the resulting overall output and efficiency is lower.

○ ◐ ● → Best	48V On-axis	48V Off-axis	HV On-axis	HV Off-axis
Transmission Integration Types	All	All	All	All
Motor Performance	◐	◐	●	●
Motor Efficiency	◐	◐	●	●
Motor Cost	◐	●	○	◐
Market Pull	○	●	●	◐

Figure 5. 48V systems are more cost-effective than high-voltage vehicle electrical systems, while still making a significant contribution to CO_2 reduction.

Summary

This highly flexible technology facilitates fast-to-market hybridization by enabling functionalities such as stop/start, regenerative braking and supplemental electric propulsion as well as pure electric driving. BorgWarner's P2 modules, with its wide range of design options, can be easily adapted to meet customer specifications and requirements. During the configuration of a design matching the specifications in each case, a wide range of factors such as the installation space available, the vehicle electrical system used and the performance characteristics required are considered to ensure optimum results.

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