# SHAFTS WITH OPTIMIZED PACKAGING AND COSTS FOR ELECTRIC DRIVES

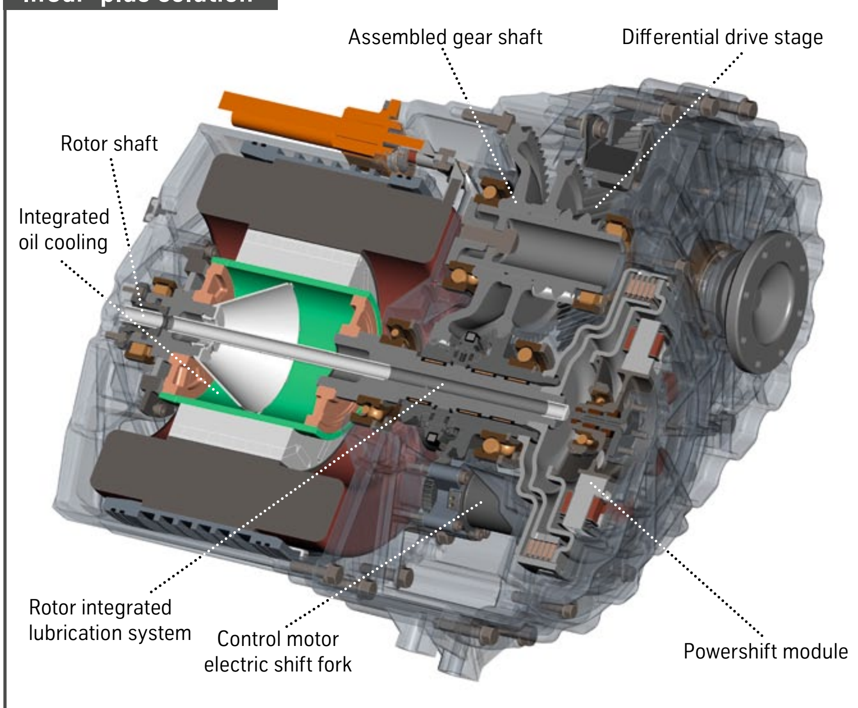
The core requirements on all electric drives are maximum efficiency and optimal power output with minimal costs and small dimensions. In the eTDC project (electromobile ThyssenKrupp Drivetrain Components), ThyssenKrupp is showing how an intelligent drive structure with innovative lightweight design components can resolve these conflicting aims. The assembled, integrated rotor/gear shaft enables tailored material selection with high economy at the same time. Thanks to the use of an optimized joining method, the omission of the transmission interface and the integration of functions, this concept offers essential advantages as regards the overall package, weight and efficiency.

At present, passenger cars driven by electric batteries are primarily fitted with one-speed transmissions with fixed, two-stage reduction and a high-speed electric motor. This configuration is usually chosen due to cost and weight reasons. However, it is subject to compromises in terms of efficiency, acceleration and the achievable vehicle speed. Two-speed transmissions can offer better efficiency and acceleration as well as a higher top speed, but previous concepts have not been accepted by the market due to cost and weight.

As part of InCar plus, ThyssenKrupp has optimized rotor and gear shafts for innovative, electrified vehicle drives, ❶. An independent drive structure was established to extensively evaluate the requirements and quantify the potentials, ❷. The essential boundary conditions and requirements on the drive are:
: small cars (B segment)
: curb weight including battery 1450 kg
: maximum vehicle speed 140 km/h
: acceleration from 0 to 100 km/h in less than 10 s
: gear changes without tractive power interruption
: conceptual flexibility and modularity
: minimum weight and package.

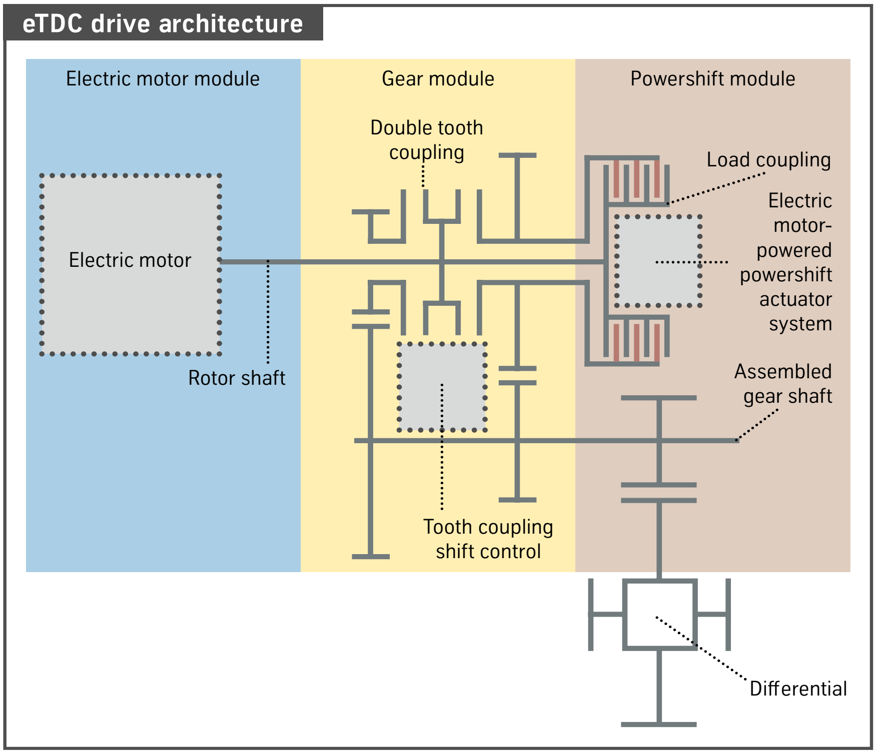
The eTDC drive structure is based on a spur gear architecture, which offers maximum gear ratio flexibility with a simple system design at the same time. The idler gears for first and second gear are mounted on the assembled, integrated rotor/gear shaft. The positively shifting double tooth coupling for both gears is located between the two idler gears. Their integration combined with the omission of synchronizer rings is possible due to the electric traction machine's precise speed regulation. This design offers significant advantages in terms of efficiency, system complexity and costs. A multi-plate clutch mounted

InCar®plus solution

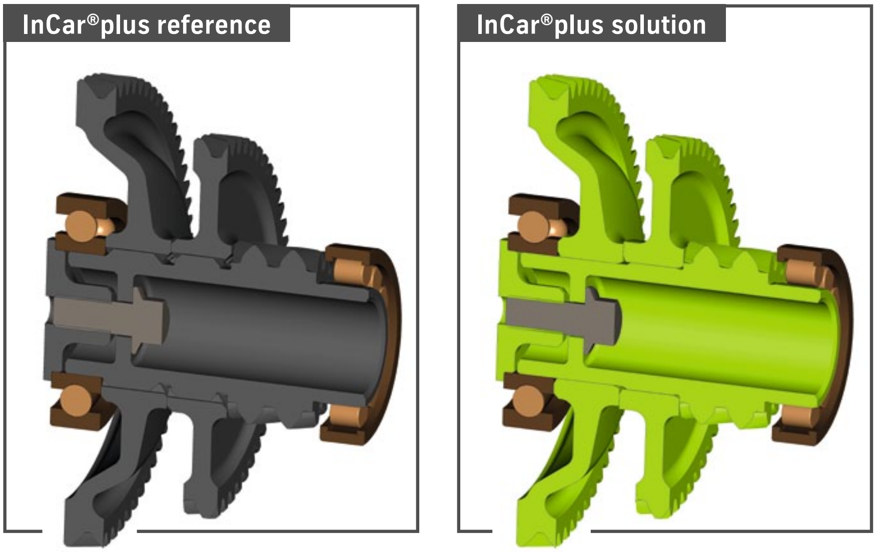



❶ Cross-section of the eTDC drive

on the face end of the rotor shaft ensures shifting without torque interruption. Simultaneous actuation of both shift elements enables a cost-efficient parking lock without package impact. Additional components can be foregone for this. Both shift elements are actuated electrically and therefore significantly reduce ancillary assembly losses. The intermediate shaft with the fixed gears is designed using an assembled lightweight structure, ❸. The resulting conceptual modularity and flexibility enable the highly efficient drive to be used in various vehicle applications.




❷ Functional breakdown of the eTDC development basis




❸ InCar plus reference gear shaft (left) and InCar plus assembled gear shaft (right)

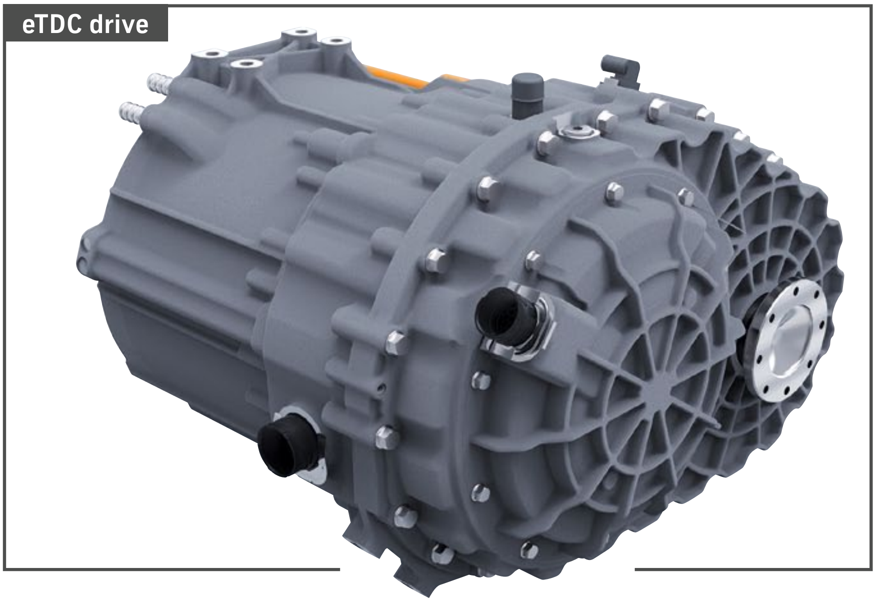
## DRIVE CHARACTERISTICS AND DESIGN

The efficient, permanently excited synchronous machine with a rated voltage of 600 V and a current maximum speed of 8000 rpm results in a high power density. It develops a permanent power output of 50 kW and 220 Nm of torque. Temporary peak values of 80 kW and 300 Nm are possible. The five-piece, assembled rotor shaft (also see article "Lightweight Rotor with Integrated Cooling System" from page 34) is the drive's central component. It comprises three different materials and is the integral link between the electric motor and the gear module.

The lubricating system can be integrated into the rotor shaft by extending the functions on the transmission side and thanks to the omission of a transmission interface which is tolerance-sensitive and thus technically complex to manufacture. The newly developed oil cooling system is also integrated into the rotor shaft. It uses the rotor's kinetic energy and very effectively dissipates the heat from the rotor's laminated core, and the thermally stressed winding heads. The oil cooling system can be engaged depending on the operating point and also enables the transmission oil to reach its operating temperature faster during the warm-up phase. This dual function integration improves the drive's electric and mechanical efficiency and minimizes the package and weight. Including the laminated core, the rotor shaft weighs just 11.4 kg.

③ shows a cross-section of the assembled gear shaft. The fixed wheels are connected by means of a press and form-fit joining process used in the mass production of engine components and has been optimized to meet the specific requirements of a transmission application. The maximum torque of 900 Nm is transmitted with a dynamic safety factor of 2 over a short joint length. This ensures a short axial length of the overall component as well as high durability at the same time. Optimized shaft wall thicknesses also effectively reduce the weight of the basic shaft. Recording the assembly force for each component guarantees complete quality monitoring during manufacturing.

One further element of the drive's efficiency is the passive oil system. In combination with the differential's pumping effect, the gravitational pressure and the suction effect of the rotor shaft, it supplies the lubrication system and the cool-




❹ eTDC has a two-speed transmission as its development basis

ing system with sufficient oil in virtually all operating states without an active pressure generator. Depending on the vehicle layout, driving situations involving high lateral acceleration may necessitate an electric auxiliary pump. This can be integrated into the design of the transmission structure. All in all, this results in a compact, modular drive layout with a very low number of components and a total weight of less than 100 kg, ❹.

## VIRTUAL VALIDATION AND TESTING

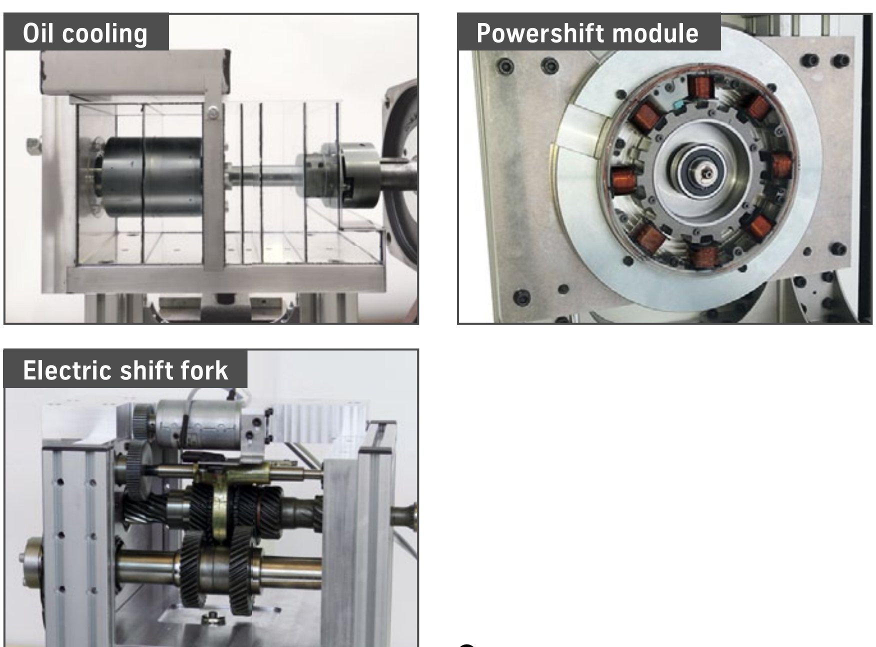
The overall system is subjected to extensive analytical and numerical validation in several development stages. To do this, comprehensive static component layouts, FEM evaluations, modal analyses and multi-body simulations were performed. The focus was placed mainly on detecting areas of resonance throughout the entire speed range and on determining the resulting dynamic stresses. Consideration was given to the bearing, housing and the changing toothing stiffness in the latter.

The overall system achieves the highest cyclical operating rates in the area of the rotor shaft in first gear. Amongst other factors, this results from the second gear's coupled assemblies at a speed of 3800 rpm. A safety factor of greater than 2 is achieved for this load case.

To determine the required mechanical, electric and thermal parameters, the electric actuators and the oil system were tested on sub-system test rigs, ❺. In combination with validated simulation models, these tests enabled the corresponding validation of functionality and implementation in the overall prototype.

To initially quantify the overall system efficiency, the engineers performed a holistic powertrain simulation based on the power loss models of all components and systems in the energy and power flow. Based on the previously defined vehicle weight of 1450 kg, energy consumption of 11.3 kWh/100 km is determined in the NEDC. eTDC therefore offers substantial efficiency potential with both a small package and low weight.

In the fall of 2014, the drive system will undergo extensive system testing on test rigs. The results obtained from simulation and component tests will be further validated there in intensive tests. The focus will be placed on the durability and operating behavior of the overall system.




❺ Development test rigs for the sub-systems