Direct-drive: the road to the future for EVs?

Driving electric vehicle wheels directly using internally mounted permanent magnet motors can overcome many EV limitations, argues Dr Sab Safi of SDT Drive Technology. By eliminating mechanical transmission components, this configuration raises efficiency and reduces complexity.

Electric vehicles are a fast-growing niche in the global automotive market in both the consumer and commercial sectors. Demand for hybrid electric vehicles (HEVs) is growing by around 20% annually, while interest in zero-emission battery electric vehicles (EVs) is also rising, but is presently an under-served market.

The main barriers in the EV market are cost, performance and availability. One way of overcoming these limitations is to use proven, efficient permanent-magnet (PM) direct-drive technologies. These gearless systems offer low implementation and maintenance costs and could overcome the barriers currently impeding mass-market EV adoption. They offer high torque and power densities in an advanced form factor, and are ideal for applications that need high torque at low speeds.

Most current vehicles rely on gearboxes and other mechanical transmission systems. Direct-drive motors mounted inside a vehicle's wheels can eliminate the need for gears or mechanical differentials and their associated energy losses. These wheel-motors eliminate the weight and manufacturing complexity of the engine, transmission, coupling (clutch or torque converter), drive shaft, and differential. The net result is lower vehicle production costs and increased reliability because there are fewer complex parts.

Various topologies are available for direct-drive brushless PM motors – for example, radial, axial and transversal flux designs. Radial-flux machines are particularly suitable for direct-drive applications because of their high torque and relatively low speed. They have been also considered for other transport and renewable energy applications. Axial-flux machines have also been used in the both low-speed direct-drive and high-speed flywheel applications.

The performance of direct-drive brushless PM machines depends greatly on their design and control. Factors that need to be optimised include the amount of magnetic material, back-emf shape, compactness, torque and efficiency.

Traditional EV powertrains consist of batteries, electric motors with drives, and transmission gears to the wheels. Each subsystem converts chemical, electrical or mechanical energy into different forms, thus dissipating energy through windage and friction.

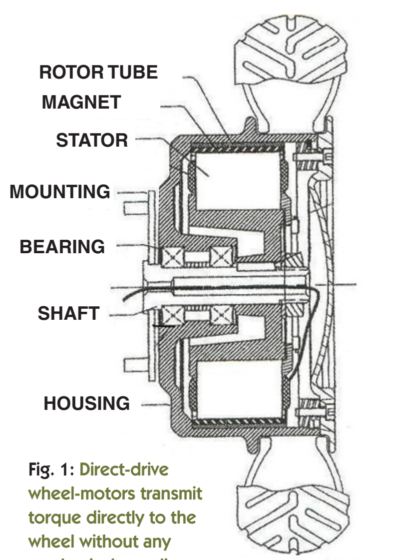

Fig. 1: Direct-drive wheel-motors transmit torque directly to the wheel without any mechanical couplings

Despite the attractions of direct drives for EV applications, they suffer from two major drawbacks – high costs (largely because of their use of permanent magnet materials) and small constant-power regions.

Detailed analysis can accomplish a thorough understanding of the design and manufacturing considerations of vehicle drive systems. Two types of plan are needed: one to design the electrical machine; the other to develop the drive process.

Under the machine design plan, it is critical to identify and quantify specific requirements such as cost, noise, vibration, efficiency, torque per amp,

Advantages of direct-drive PM machines

- Radial/axial flux PM motors and alternators offer exceptional power densities and efficiencies in a pancake form factors.
- Brushless PM motors increase efficiency, safety and reliability.
- High stall torques allow high performance and rapid acceleration that is complemented by optimal operation at both low and high speeds.
- Segmented bar winding designs (one or two layers) yield high filling factors, short end-windings, low leakage inductances, and good cooling.
- Scalable architectures are easily configurable for a wide range of applications.
- Hall effect commutation allows high torque at low speeds, or sensorless control of high-speed systems.

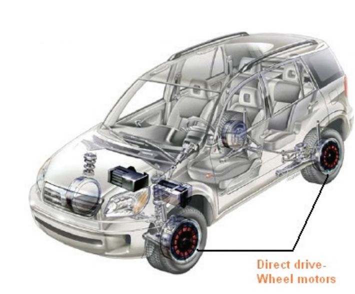

Fig. 2: How the various elements in SDT's direct-drive system interact

continuous and peak power outputs, back-emf, torque ripple, reliability and robustness. This plan also needs to identify and define power densities, thermal and electromagnetic designs, and voltage and current supplies. And, of course, it needs to explore different machine types (PM, induction, switched reluctance, synchronous reluctance, and so on).

The drive process development plan needs to define requirements for rotor and stator manufacturing, and for materials.

Once the product design and process development plans have been devised, one can then create a matrix that will aid in matching the machine type to specific requirements.

Figure 1 shows the basic construction of a direct-drive wheel-motor. The torque is transmitted directly to the wheel without needing reduction gears or flexible couplings. It therefore represents a simple drive system that solves problems such as transmission losses, noise, maintenance, and the mass and volume of mechanical power transmission systems.

The rotor of the wheel-motor contains the permanent magnets and is fixed to the rim of the wheel. To reduce the size and mass of the direct-drive brushless motor and to boost its efficiency, high-performance Nd-Fe-B rare-earth permanent magnets are typically used.

The stator is inside the rotor and is fastened to the wheel's half-shaft. A pair of ball bearings allows the rim to rotate with respect to the fixed half-shaft. The motor is fed by a DC/AC converter, operating at high switching frequencies and connected to the vehicle battery.

The short lengths and wide magnetic teeth flux paths of direct-drive brushless PM motors contribute to their good performance. The concentrated winding arrangement, combined with the shape of the stator teeth, gives a high torque density. The supporting teeth between each phase have a beneficial effect on the flux in the stator core, and a cooling effect on the winding components close to it.

Safi Drive Technology (SDT)* is working on direct-drive PM drive systems for electric vehicles (see Fig 2). It is focusing its efforts on the technologies that are critical to making direct-drive machines competitive with conventional machines in terms of cost, performance, and reliability.

Direct drive is coming of age. It encompasses the entire spectrum of drive powers and sizes. High performance is now possible at a substantially lower cost than conventional gear-motor drive systems. Direct-drive machines reduce assembly, tuning and maintenance operations, as well as reducing operating costs. D&C

* More information is available from www.sdt-safidrivetechnology.co.uk