Winning the power struggle

Hybrid synchronous electric motors could be a breakthrough technology for electric vehicles and hybrids. Ian Adcock finds out more from Dr Robert Brand of Vacuumschmelze and drivetek's Drs Andrea Vezzini and Ludvica Baselgia

All vehicles – irrespective of whether they are powered by petrol, diesel, hybrid or electricity – face a common challenge: how to maximise the power output from electric motors, without unduly increasing their size and weight.

Those motors could be used to power either the vehicle or elements such as seating, steering or air-conditioning systems, as manufacturers try to maximise efficiency by reducing the drag on engines caused by powering auxiliary systems. This has led to the current trend towards hybrid-excited synchronous motors.

Unlike more conventional electric motors, these deliver torque comprising of two elements: a magnetic moment (a force exerted on a live conductor in an air gap field, generated by means of a permanent magnet) and a magnetic reluctance (the force operating between magnetisable iron sheets).

With a high starting torque from zero rpm up to the 'corner' point, and a constant power speed range above the 'corner' point, up to maximum speed, it makes them ideally suited for both electric vehicles and hybrids.

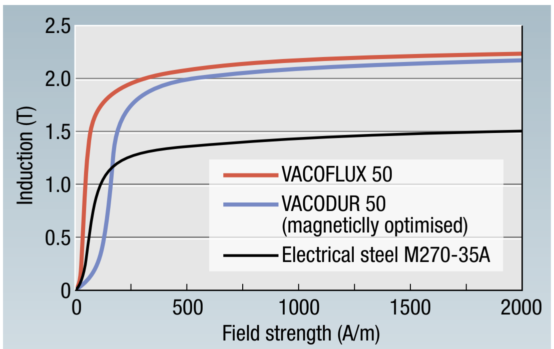
Technology breakthrough

In a technology breakthrough, drivetek ag has developed a scalable motor that, says chairman of the board Prof Dr Andrea Vezzini, is adaptable to various power and torque requirements. "This is achieved by changing the motor length, for example. The conceptual design of the drivetek motor is consequently scalable. Not only the stator and rotor, but also mechanical parts can be scaled, with no changes in tooling."

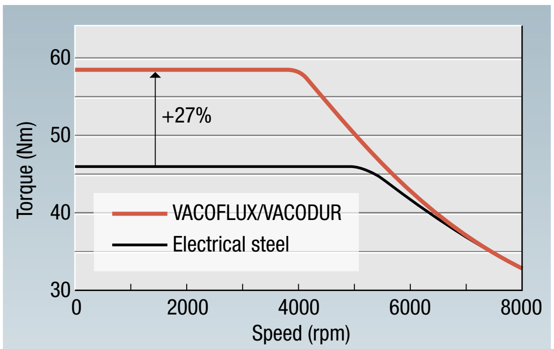
The first application is on two wheels, rather than four, in the Quantya electric motorcycle. As his colleague Dr Ludvica Baselgia explains: "Quantya was using high performance permanent magnet (PM) motors, but couldn't get the required performance within their weight limits. Weight and its distribution is one of the most important factors for such high-performance sports 'bikes and drivetek was able to design a motor to meet their demands." (See graph 2)

To achieve the best combination of magnetic moment and magnetic reluctance, JMAG finite element simulation software was employed for the analytical optimisation of the magnetic circuit.

A key element to increasing torque, without a subsequent increase in the motor's size, was employing cobalt-iron (CoFe) materials supplied by Vacuumschmelze GmbH & Co KG, in place of silicon-iron (SiFe). This was considered vital in sports cars where weight is at a premium. "Drivetek is setting up mass production in Europe," reveals Vezzini, "for first customer serial applications in the third quarter of this year, although non-disclosure agreements prevent me from saying who. We also have



Graphs 1 and 2 depict increased performance of drivetek's motor, when compared to conventional technology.



prototypes with customised torque-speed characteristics available."

Key materials

According to Vacuumschmelze's product marketing manager Dr Robert Brand: "Advanced cobalt-iron alloys have a significantly higher saturation magnetisation than conventional electrical steel, such as M270-35A. Of these, our Vacoflux 50 achieves the highest saturation magnetisation of all known soft magnetic materials, at 2.35 T, and can be used in the production of electric motors and generators, which deliver maximum power densities."

CoFe alloys have been used in the aviation industry for many years, owing to their lower weight advantage. To meet the increasing demands for power density and energy efficiency, they are also increasingly being used in other industries, such as in generators for auxiliary power units and in high-end automotive applications, such as sports cars and luxury vehicles, or for linear motors in automated production systems.

As Brand points out, Vacodur 50 and Vacodur S+ are in the same family of CoFe alloys as Vacoflux 50, "with high saturation magnetisation and outstanding tensile properties, and yield strengths from 390 to 800 MPa. It makes these materials extremely useful for rotor applications, particularly in high speed and/or high-torque motors." (See graph 1)

Multiple approaches

To ensure that the outstanding material properties of CoFe alloys are retained when used for lamination stacks, VAC also manufactures complete rotor and stator assemblies, with lamination strip thicknesses between 0.1 and 0.5 mm. Depending on the number of units required, a variety of manufacturing technologies are used: electrical discharge machining (EDM), wire-cutting, laser cutting, single-slot die cutting and complete lamination blanking.

A variety of optimised bonding

Prof Dr Andrea Vezzini CV

Bern University of Applied Sciences, Quellgasse 21, CH-2501 Biel, Switzerland; MSc '91, PhD '96 from ETH Zürich, Switzerland. MTE (Mastering Technology Enterprises) from IMD Lausanne in 2002
Since 1996, Professor for Industrial Power Electronics at Bern University of Applied Sciences. Visiting Professor at GM Advanced Technology Centre in 2003 and Distinguished Visiting Scientist at CSIRO 2007. Chairman of the board and founding member of drivetek ag, and member of the board Integrated Power Solutions AG In 2001. Received the 'Swiss technology Award' for the drivetrain of the first commercial electric glider. He holds six patents in the field of electric drives and battery power management systems
His current research projects cover hybrid permanent magnet synchronous reluctance motors for hybrid and electric cars.

methods, including adhesives, welding or automatic stacking, are available, depending on the particular application.

In addition to producing advanced soft magnetic alloys, VAC also manufactures high energy density rare-earth based permanent magnets of samarium-cobalt (Vacomax) and neodymium-iron-boron (Vacodym). Due to their high homogeneity and low variability of properties, these magnets are frequently used in servomotors and heavy-duty applications, such as wind turbine generator systems.

Dr Ludvica Baselgia CV

Educated as a physicist at the University of Zurich, Switzerland
PhD degree in the field of superconductivity at the University of Utah, Salt Lake City, USA
Held positions in R&D in industry with different companies
Bruker Biospin AG: worked in the field of cryogenic high frequency signal detection systems for nuclear magnetic resonance (NMR)
40th Annual R&D Awards in 2002, with a high-resolution NMR Cryoprobe
Contelec AG: in the field of angle sensors
2009: joined drivetek, responsible for electrical machine design, with emphasis on design & simulation of permanent magnet machines for special applications.

A further option, says Brand, is the production of complete magnetic systems, which is particularly useful when permanent magnets need to be assembled and secured into rotors, using adhesives. The complete laminated rotor assembly encasing the embedded magnets, together with the laminated stator stack, can be manufactured at a single-source location.

CoFe materials optimise motors

The existing drivetek motor is an 8-pole synchronous machine, with permanent-magnet excitation from magnets that are inserted into the rotor. The stator and rotor are made from 0.35mm thick laminations of silicon-iron, with 3% Si content (electrical steel M270-35A); the magnets are NdFeB rare-earth magnets, with a remanence of 1.26T and an operating temperature range of up to 170°C.

The drivetek motor was optimised by changing the material used for the stator and rotor, and improving the design. “First, the electrical steel was replaced with the same thickness of Vacoflux 50 (stator) and Vacodur 50 (rotor), which offers optimum magnetic properties and mechanical strength. Stronger magnets with 1.36T remanence compensate for the decrease in induced voltage that occurs when the saturation flux density in the rotor is increased. The use of the new material alone resulted in a 22% rise in torque from 46.1Nm to 56.2Nm, states Brand.

“Secondly, we wanted to increase the torque, but increasing the magnetic torque would have caused the induced voltage to increase, which we didn’t want. But, by increasing the volume of the magnets by 12% and including a variable air gap of up to 1mm, we were successful in increasing reluctance torque,” he explains.

The motor containing the Vacoflux and Vacodur components has a maximum torque of 58.5 Nm, compared to 46.1 Nm for electrical steel – a 27% increase. Also, the motor reaches its nominal rating at lower revs and thus achieves maximum power at an earlier stage. Higher torque is not achieved in the field weakening range above the nominal rating, since the output of the motor is limited by the inverter.

"Graph 3," explains Ludvica Baselgia "clearly shows that higher magnetic flux densities are achieved in both the stator and rotor with Vacoflux and Vacodur.

No cutting corners

"Electrical steel reaches a maximum of 1.7 T in the stator tooth and yoke, while CoFe materials reach flux densities of up to 2.2 T. In the electrical steel rotor, the lower flux density enables saturation to occur at the thin section SiFe surface layer; while, in the CoFe motor, stronger magnets of Vacodym 669 TP are used to achieve the higher saturation level of the thin section Vacodur 50 surface layer.

"The magnetic flux density in the stator teeth and yoke is already optimised, so increasing the slot area and modifying the coil doesn't increase the torque. Moreover, both motors show comparable efficiency; the copper losses in the windings dominate and are identical in each design, while iron losses in the electrical sheets are lower when CoFe alloys are employed."

In summing up, Vezzini says: "The results presented here are based on finite element method (FEM) calculations, which in our experience provide a realistic reflection of motor data. To verify that, we built a motor incorporating Vacoflux and Vacodur, and measured this as a comparison to the existing electrical steel motor. "As an alternative to increasing the torque, while retaining the design envelope, there is a theoretical possibility of a 27% increase in power density, with a similar decrease in volume. It's conceivable we could maintain torque, while reducing design space and weight.

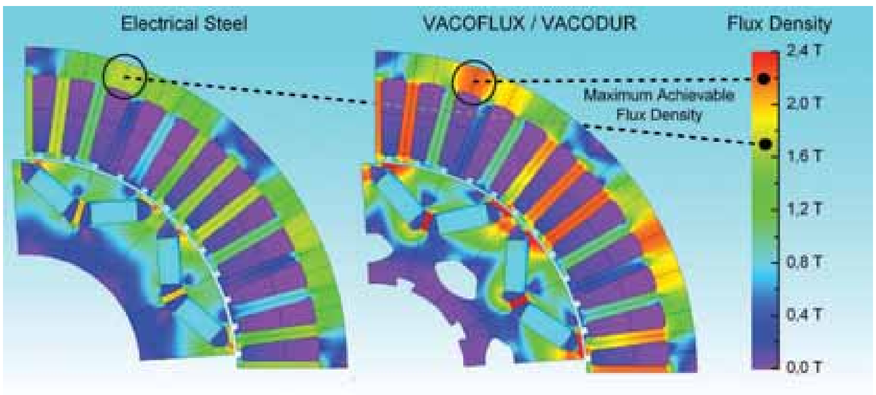
Attaining targets

"Further optimisation could be achieved by using thinner laminations of 0.1mm or 0.2mm, as iron losses decrease more sharply for CoFe materials, with lower strip thicknesses than for electrical steels," he adds.

With more OEMs looking towards some form of vehicle electrification to help improve their corporate average fuel efficiency and reduce emissions, it is technology such as drivetek's latest motors that will help them achieve those targets.

Dr Robert Brand CV

Born in 1966 in Aschaffenburg, Germany, Dr Brand is head of business development specialising in materials & parts for Vacuumschmelze GmbH & Co. KG. He gained a PhD in physics at Augsburg University in the field of disorder dynamics of plastic crystals in 2000 before joining Vacuumschmelze in research and development of magnetic materials, focusing on soft magnetic composites He has been in product marketing since 2004, developing new sophisticated applications in cooperation with customers worldwide.



Graph 3 shows higher magnetic flux density.