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European Green Cars Initiative

SEVENTH FRAMEWORK PROGRAMME

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Materials and drives for High & Wide efficiency electric powertrains

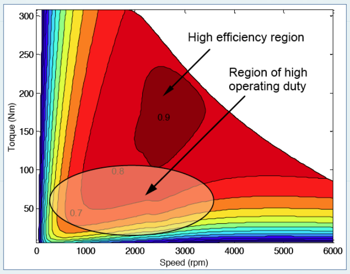
Introduction

At present, motors for FEV (Fully Electric Vehicle) and HEV (Hybrid Electric Vehicle) applications develop their highest efficiency of around 93~95% within a speed range of typically 1/4 to 1/3 of the maximum rotating speed, and at an ideal torque, whereas in real usage - in the majority of driving cycles - the motor operates at a wider range of speeds and at partial load (low torque) resulting in lower overall efficiency.

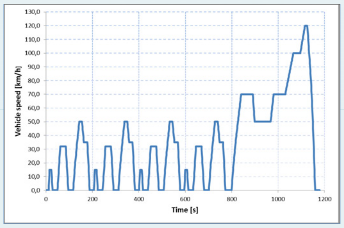
Hi-Wi addresses the mismatch between the region of HIGH efficiency and the WIDE region of frequent operation with advances in the design and manufacture of drivetrains optimized for performance over a whole drive cycle rather than a single point.

In addition to efficiency gains, Hi-Wi couples its novel design approach to developments in magnetic materials which utilize nano-scale micro-structural control to deliver reductions in the consumption of rare earth elements. This is of interest due to the restricted nature of their supply chain and the rapid fluctuations in price which have been associated with the increase in use of these materials.

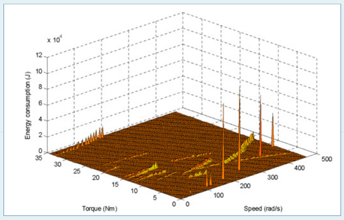
Problem: Current drivetrains are not optimised for real drive cycles



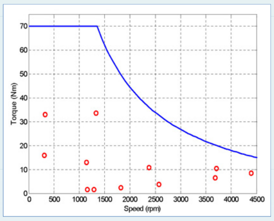
Drive cycle analysis



NEDC drive cycle



Energy consumption over NEDC drive cycle.

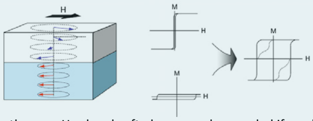


Optimisation simplified by reducing NEDC cycle to 12 representative points

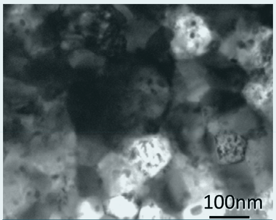
Developments in magnetic materials

Exchange coupled nanocomposite materials offer the opportunity of either passing the theoretical limit to NdFeB energy product of 485 kJm^{-3} or reducing the amount of rare earth elements required while maintaining performance. Developing a process route to allow the produciton of bulk nano composite magnets is of interest

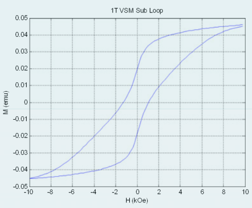
The addition of Dy to NdFeB magnets is required to improve their coercivity and allow them to operate at elevated temperatures. Dy is most effective at grain buondaires at he edge of magnets. Heat treating coated magnets could reduce Dy consumption by over 75%

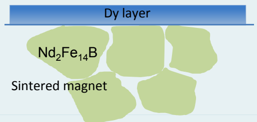


Exchange coupling theory – Hard and soft phases can be coupled if small enough [2]

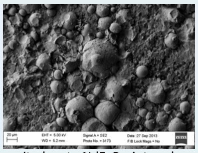


Laser annealed nano-composite sample

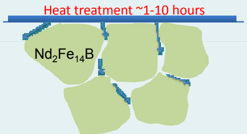




1) Thin dysprosium layer deposited on surface of sintered $Nd_2Fe_{14}B$ Magnet

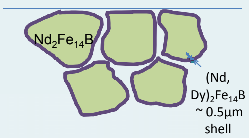


Dy deposited on to NdFeB sintered magnet



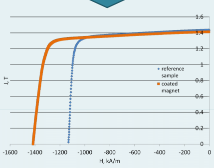
2) Heat treatment causes Dy to diffuse through grain boundaries

Heat treatment at 900 °C for 6 hours followed by 500 °C for 30 minutes



3) Edge of $Nd_2Fe_{14}B$ grains undergo substitution to form $Dy_2Fe_{14}B$ layer:

Maximum improvement in temperature performance and coercivity for minimum Dy consumption

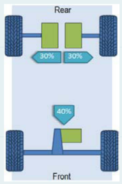


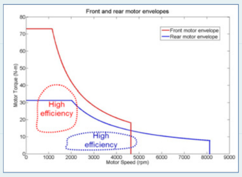
Coercivity enhanced by 25% by addition of the equivalent of 3.5 µm of Dy.
This represents an 85 % reduction in the use of Dy relative to a magnet of similar performance made using binary alloying

On-going and Future Work

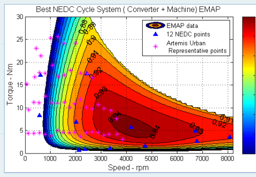
- Assessement of HiWi motor designs over driving cycles
- Validation of Optimisation Process
- Production of reduced Dy magnets for HiWi motor

Optimisation of a three motor drive train over NEDC and Artemis drive cycles



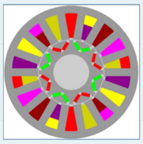


Drive train configuration: two motors optimised for different speed ranges

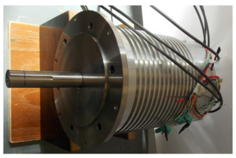


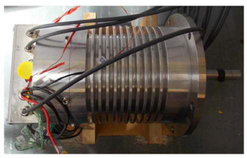
Efficiency map for optimised drivetrain

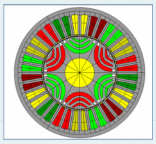
Outcomes



Prototype front motor







Prototype rear motor

Conclusions

The reduction of driving cycles to key representative points in the torque, speed envelope and the development of new optimization tools has allowed drivetrain design to be optimized over a realistic usage case and has allowed the effect of a dynamic torque split across motors of differing characteristics to be assessed.

The most suitable topologies have been found to be a stator mounted permanent magnet machine which provides most torque at low speeds and a permanent magnet assisted synchronous reluctance machine which is more efficient at higher speeds while not requiring NdFeB magnets the use of a dynamic torque spilt for the front and rear motors have been predicted to offer an improvement in efficiency of 0.95 % over the NEDC cycle.

Two new process routes have been investigated for the production of magnetic material with reduced rare earth content. The most promising route for the production of bulk magnets for use in electric drives is the deposition of Dy followed by annealing to induce diffusion of Dy down grain boundaries.

EPSRC Engineering and Physical Sciences Research Council
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FIAT
CRF CENTRO RICERCHE FIAT
CEDRAT
SIEMENS
UNIVERSITY OF CAMBRIDGE

[1]Hirota K, Nakamura H, Minowa T, Honshima M, Coercivity Enhancement by the Grain Boundary Diffusion Process to Nd–Fe–B Sintered Magnets, IEEE TRANSACTIONS ON MAGNETICS, VOL. 42, NO. 10, 2909- 2911, 2006
[2]Liu, J. *Nanoscale Magnetic Materials and Applications*. *Springer* (Springer: 2009).doi:10.1007/978-0-387-85600-1