UKMS Seminar Report: Magnetics in Future Energy Systems

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In October 2019, the Society organised a 1-day seminar with speakers addressing a wide range of topics under the umbrella of the role of magnetics in the future of electric power generation. The meeting was held in the very impressive venue of the Durham Town Hall in the centre of the city.

The morning session was chaired by Dr Arwyn Thomas of Siemens Gamesa Renewable Energy Ltd, who introduced Prof Simon Hogg of Durham University to welcome the crowded room of delegates. Simon briefly spoke about some of the work that University of Durham is undertaking, as well as saying a few words about the lovely city of Durham.

Speakers (L – R): Jiawei Mi, David Collier, Stuart Bradley, Arwyn Thomas (Chair), Glynn Cooke, Jonathan Godbehere, Damian Hampshire, Hamed Bahmani (Chair), Xiaoze Pei, Seiji Okabe

Simon was followed by Glynn Cooke of Magnomatics, whose talk *Large Scale Magnetically Geared Generator* described the development of a very efficient (>99%), large scale magnetically geared generator that currently is able produce 500 kW with a torque of 200 kN-m. After explaining the operation of the Magnomatics Pseudo Direct Drive, he explored the design simulation work that Magnomatics had performed in electromagnetic, thermal, structural and fluid dynamics to optimise the design. The machine had been manufactured at ATB Laurence Scott in Norwich and subsequently tested both at the Offshore Renewable Energy Catapult facilities in Blyth and Norvento Enerxia in Spain, with excellent results and expected performance.

Glynn was followed by David Collier from Minesto. David's talk *Tidal Stream Power* was about the exciting underwater kite technology that the company are developing to create renewable energy. After showing the resource available through tidal stream energy, David explained the design, which looks like a glider, and exploits the currents in the ocean to

achieve higher speeds, compared to a conventional fixed axis turbine, as it describes a "figure of 8" path. The on-board turbine generator is connected to a flexible coupling attached to the sea bed, which then delivers power to the surface. He went on to describe the construction, assembly and testing of the prototype device off the coast of Wales. The first demonstrator project will be in the Faroe Islands, where 2 of the DG100 devices will be installed.

The final two talks in the morning covered the development of magnetic materials for generators and motors. Seiji Okabe of JFE Steel's talk *Magnetic Properties of 6.5% Silicon Electrical Steel and its Applications* covered the capabilities and advantages of the relatively new generation of 6.5% silicon steels. Firstly, he briefly described the creation of JFE from two of Japan's most prestigious steel companies, Kawasaki and NKK, before introducing the new material. Seije then emphasised the excellent properties of the new steels in high frequency electromagnetic devices. JFE is producing two types of high silicon electrical steels: JNEX, with uniform distribution of 6.5 % silicon content across the lamination thickness, and JNHF, with gradient silicon concentration in the sheet thickness. As well as exhibiting improved magnetic permeability at lower fields, requiring less MMF to achieve the same flux density, they also offer low magnetostriction and iron loss compared to materials used in most present day machines. The increased low field performance comes at a price – saturation flux density is only 1.8 T – but this can be improved by slightly reducing the silicon content. It is expected that a saturation density of 2 T will be achieved shortly without compromising other performance. Seiji finished his talk by showing comparison performance for a particular lamination design.

Seiji was followed by Jiawei Mi of University of Hull whose *High Performance Magnetic Materials for Sustainable Energy Applications* gave a very comprehensive review of the range of permanent magnet materials available for electrical machines used in power generation. The talk showed the advantages of a REPM based generator over an equivalent wound machine – lower volume and weight, better efficiency and torque density, lower internal heat and easier assembly and maintenance. But, it comes at a cost – a 3 MW direct drive machine uses 1.5 Tonnes of REPM, which is a significant cost for the whole machine. He also outlined both the benefits and disadvantages of each type of permanent magnet material. In particular, he discussed how the microstructure affects coercivity and the hydrogen-disproportionation-desorption-recombination process (HDDR) to produce ultrafine grains in REPMs. Finally, he discussed some of the actual and proposed advances that have recently been made in REPM materials, such as melt-spinning.

After lunch, Dr Hamed Bahmani of University of Durham took over the chair and introduced the first speaker in the afternoon, Stuart Bradley of the Energy Systems Catapult. Stuart set the theme for the early part of the afternoon in his talk *Electrical Machine Development Trends for Transport and Energy*. This talk showed that all forms of transport and energy production still require considerable improvement to meet the targets set for greenhouse gas emission. For example, global shipping currently produces more than 11 million Tonnes

of CO2. Motors in different transport sectors vary widely in power to weight ratios and the best performances, in both automotive and aerospace, have been achieved by axial flux architectures. But Stuart did have some good news as well – the 2025 EV target of 7 kW / kg mass for new vehicles had already been achieved during 2019. Another significant component of the talk was the requirement to design for manufacturing and service, especially on offshore wind platforms, and end of life re-use and recycling.

Following on with a similar theme, Jonathan Godbehere of MDL presented the capabilities required for software design tools to achieve an optimal machine design. Jonathan's talk *Advances in Electrical Machine Design for Electrification* was based around the Motor-CAD software developed by MDL, but he showed that links to other software, such as Ansys and Romax products, were very important. He illustrated his talk with examples of finite element / finite volume based simulations for electromagnetic, structural and thermal design, as well as simpler, fast thermal analysis using lumped parameter representations of the machine. In particular, Jonathan showed how Motor-CAD was used to estimate inverter induced loss in soft materials and how REPM is used in a wide variety of different machine topologies. He also then looked at the wider issue of making the machine design suitable for its operation as part of a more complex system.

The final session of the afternoon saw a shift in emphasis with two speakers addressing the impact superconducting materials may have on magnetics in future energy systems. Dr Xiaoze Pei of the University of Bath looked at one usage of high temperature superconductors (HTS) on power transmission with a talk entitled *Superconducting Fault Current Limiters*. After explaining the purpose of fault current limiters and discussing the different types of HTS wires and tapes, she gave a detailed presentation of a novel design of 11kV superconducting fault current limiter (SFCL), where the superconductor is used as a part of the main power transmission circuit in a DC link. This is very challenging as the current does not go to zero, unlike an AC breaker where it occurs twice in a cycle. In this case, the high current density during the fault is sufficient to make the HTS go to its normal state. The prototype manages to interrupt 500 A DC fault current within 3.5 ms – a very impressive performance. Xiaoze also discussed the alternative configuration where the fault current induces current in a superconducting coil, resulting in magnetic saturation of a connecting yoke and a significant change of impedance in the circuit.

Prof Damian Hampshire, head of the superconductivity group in Physics at Durham University, was the final speaker. Damian chose a provocative title for his talk *How Long Should We Wait for Magnetically Confined Fusion?* since the promise of cheap, clean energy through nuclear fusion always seems to be "about 30 years away". Damian reviewed that current operating experimental fusion machines, such as JET at the Culham Laboratory in Oxfordshire, and then discussed the design and progress of the International Thermonuclear Experimental Reactor (ITER), currently under construction in France. Fusion occurs only at very high temperatures and there is a requirement to keep the plasma suspended away from its containing vacuum vessel – hence the need for magnetic confinement. With ITER, the only viable solution to produce a strong enough field is to use superconducting coils. Damian's group has been working on both design and testing of some of the massive coils that ITER requires and he presented some of the results for individual superconducting wires and demonstration coils. To partly answer his own question, he pointed out that ITER, which should be operational in the mid-2020's is still an experiment and will not produce energy that is used directly in power generation. However, it is the first experiment that is expected to be energy positive (output energy > input energy). The next planned international experiment, DEMO, should be the first tokamak that is actually producing electricity by 2040 – though still as an experiment and not commercially. And the answer to the question, "In a democracy, the public decides!" – Where do you want your taxes spent?

After thanking all the speakers, Hamed adjourned the meeting to reconvene on the University of Durham campus. After a pleasant stroll through the city, the delegates split into two groups according to their interests. One group were given a tour of the superconducting laboratory facilities, which includes a number of very high field superconducting magnets for testing materials. This includes a cross-field design so that HTS samples can be easily rotated in the field to determine the angular dependency of the critical current density.

The other group toured the engineering labs, including the impressive wind tunnel, solar car project and the energy conversion laboratory. The Wind Tunnel Laboratory at Durham houses a large two metre area tunnel suitable for devices such as 40 % scale road vehicle models, small wind turbines, building models, aircraft and sailing ship models. The Energy Conversion Laboratory currently houses a range of modern electrical machines, AC and DC power supplies, high power drives, AC and DC measuring instruments, and Epstein frame and single strip tester for magnetic measurement.

These tours concluded a thoroughly enjoyable, informative and varied seminar, where there were many opportunities to learn of relevant technologies outside the delegates' normal day-to-day work.

About the UK Magnetics Society

People involved with the UK Magnetics Society believe that magnetism in all its forms is an amazing force, and that by understanding and harnessing it people can deliver amazing things. We are called the UK Magnetics Society, but only because we started there. There are no limits to members, delegates, events or content – as our resources allow, we always have and always will engage worldwide, supporting magnetics professionals in all fields or countries, and in industry, government and academia.

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