Seminar Report: MMA'19: Magnetic Materials and Applications 2019

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The UK Magnetics Society held the latest in its Magnetic Materials and Application series in perhaps its grandest location to date last September, thanks in no small part to the efforts of Laboratorio Electrofisico (LE) in celebration for their 60 years of trading. In an unusual coincidence it was also Bunting Magnetics' 60th anniversary. The event was organised by Co-Chairs Matthew Swallow of Bunting, Nick Simpson of Bristol University, and Nona Stanciu of LE.

In addition, part of the seminar was given over to several talks as a dissemination session for the EU's NOVAMAG project, which aimed to create novel, critical materials free, permanent magnets with high anisotropy phases.

With the beautiful Villa Ida Lampugnani as our venue for 2 days, UK Magnetics Society Chair Jeremy Tompkins opened the event by summarising the value to Europe of magnetics and how great it was to see so many people from the European community utilising the Society to gain deeper knowledge in this industry, and then handed over to Nick.

Some of the delegates in the garden of the Villa Ida Lampugnani

Our first talk, *PM Rotors In-Situ Magnetization for Powertrain Motors*, was from Federico Russo of LE, and focussed on the energy efficiency considerations of magnetising systems. As all the energy discharged into a coil is lost as heat, and that heat has to be removed from the system, it is critical that a careful balance of energy in and out is maintained. As fixtures change their behaviour when warm, maintaining a constant fixture temperature is imperative. With the introduction of 3D printing technologies employed by LE, more complex winding is now possible with more rectangular wire and hence the fill factor is improved, and the energy usage is reduced.

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Our second and most passionate speaker was Badrinath Veluri from Grundfos A/S speaking on *Rare Earth Permanent Magnets: A Journey Towards Sustainability*. Grundfos' owners have taken the decision to apply their personal goals to their business goals and they are committed to controlling the production of all of their materials and particularly the magnets within systems to prevent excessive damage to the Earth and to make the materials that we have go further for longer. This is a decision that has cost in terms of their end of life recycling program, but they believe that this is the right way to go about the business they are in. They are committed to standardising the rare earth manufacturing route, making it more transparent and secure. Badrinath asked "Is it enough to be efficient" and went on to talk about the massive strides made in the last 20 years where energy usage has been reduced by 83%. A similar reduction in the next 20 years will only give a 10% improvement, so other areas need to be looked at for total system savings, leading to Grundfos' lifecycle management process. For those who wish to be involved with this process, Grundfos have introduced ISO/TC 298, "Standardization in the field of rare earth mining, concentration, extraction, separation and conversion to useful rare earth compounds/materials (including oxides, salts, metals, master alloys, etc.) which are key inputs to manufacturing and further production process in a safe and environmentally sustainable manner."

Our most controversial speaker Govind Bisht from LE then took the stage to talk about modelling of isotropic elements within what is normally assumed to be a fully anisotropic magnet in *Magnetization Models for Mixed Anisotropic and Isotropic Magnets*. This work was mainly focused on ferrite magnets because it has been found that production ferrite magnets must have isotropic regions, proven by the fact that real world tests do not match magnets modelled as 100% anisotropic. Govind's goal was to try to quantify the isotropic regions and come up with a model that would simulate them to balance test data with modelled data. This approach was challenged in great detail by the audience and further discussion in this

area was had over the course of the two-day event. It was great to see a talk get so much reaction from the crowd!

After an excellent lunch we moved into the NOVAMAG dissemination session. The since completed EU funded project aimed to create novel, critical materials free, permanent magnets with high anisotropy phases. NOVAMAG developed an automated large computational screening followed by experimental screening of new and novel intermetallic compounds with uniaxial structures (with high saturation magnetisation, magnetocrystalline anisotropy and Curie temperature), which can be used for the rapid development of high performance permanent magnets without the use of critical raw materials (CRM).

In the first talk, we were treated to a rare insight into some of the high technology that keeps Vacuumschmelze at the head of the sintered NdFeB market, with a talk from Christoph Brombacher on *Raw Material Efficient Production Techniques*. I had personally previously looked at the N55SH grade with wonder and scepticism, but Christoph's talk shone light on their technical success. With the theoretical limit of NdFeB being approached, what can be done to continue to push the boundary of this material? Terbium is better at increasing coercivity than Dy but at an increased cost and is a potential material for the future. This can be grain boundary diffused in the same way as Dy but under slightly different processing

conditions. The key to Vacuumschmelze's success is that they are able to combine GBD and grain size control to get to the N55SH grades, so prized by the high end motorsport users. Following on from this, Jürgen Gassmann of IWKS offered a different material route in his talk on *Securing the Supply Chain of Rare-Earth Elements for Nd-Fe-B Type Magnets*. This route is not intended for high end applications, but to try to bridge the gap between low cost ferrite and high cost, high energy ND magnets. If a Lanthanum or Cerium magnet could be made using $8 raw materials rather than $60 to make a 35 MGOe magnet, this would change the face of magnet usage worldwide. This was a significant part of the NOVAMAG development project and a piece of work I am very interested in following.

The second talk from José Manuel Barandiarán of BCMaterials – *NOVel, critical materials free, high Anisotropy phases for permanent MAGnets, by design (NOVAMAG)* – described the goals of the project to be to theoretically design and predict new phases and microstructures for production and test. The project concentrated on (Rare Earth)(Iron)(X) combinations, and mainly focussed on La and Ce.

Next, Heike Herper of Uppsala University gave perhaps the most theoretical of all the day's talks with *Theoretical Characterization of New Phases for Permanent Magnets*. She really

Speakers (L – R): Patrick Aeschlimann, Dimitris Niarchos, Matteo Pistaffa, Andrea Del Prete, Federico Russo, Chris Riley, Rupert Cruise, Jürgen Gassmann, Lydia Pickering, Martin Krengel, Govind Bisht, Jeremy Thomson, Maria Francesca Dell'Acqua, Christoph Brombacher, Thomas Schrefl, Heike Herper, Alastair Stewart, Matthew Swallow (Chair), Nona Stanciu (Chair), Nick Simpson (Chair), José Manuel Barandiarán (missing: Badrinath Veluri, Mark Senti)

drilled down into the atomic structure of the magnets and the impact of this on the phases of the metallic compounds created. Of all the thousands of hours of computation and analysis, five contenders emerged as possible new magnet materials. Sadly, they still need much research, but the team is hopeful that this will yield an inter magnetic strength material to utilise some of the cheaper and more abundant rare earth materials.

After a much needed coffee break, Thomas Schrefl from Danube University Krems kicked us back off with *Modelling of Microstructure for Optimum Hard Magnetic Properties*, a look at how to use modelling systems at the different levels of analysis. Using three analysis tools: Heisenberg at 10^{-9} to look at atomic structure, FEA at 10^{-6} to examine metallic structure, and Maxwell Equations at 10^{-3} to look at properties allows us to infer bulk properties from the microstructure using computer analysis and look for an output on coercivity. Whether or not the microstructure warrants further investigation depends on the coercivity output.

Dimitris Niarchos of NCSR Demokritos explained in *Experimental Screening of Theoretically Predicted Phases* that he is keen to exploit the fact that Nickel and Iron are two of the most abundant materials on earth, and that it possible to replace two of the Cobalt parts in Sm_1Co_5 to produce $SmFeCo_3Ni$ and greatly reduce the cost. The massive data analysis required was given a boost by the work on the human genome project, analysing magnetic materials using distributed computing on personal computers. NOVAMAG also borrowed from the metallic combination sciences to use deposition technology in the opposite way to how it is normally used. By trying to create different ratios of deposition rather than a homogenous blend they can generate 100 different blends in a single pass and more easily conduct analyses. The best performance defined as to be the magnet with the highest magnetic moment, was found by taking Iron and Cobalt and depositing different blends. A similar approach was used to find $Nd_1Fe_{12}N_x$ which seems to have a similar Br to NdFeB and coercivity to match SmCo. Very interesting for the future of magnetic materials!

Our penultimate talk of the day, from Bahar Fayyazi from the Technische Universitat Darmstadt, *Fabrication of New Phases with High Coercivity*, focused on a different route to analysing new potential materials. Instead of looking at the magnetic properties, their team looked at using the mechanical properties. In a similar way to how steel is cold rolled or hot pressed, the potential magnet materials are subjected to the same machinal processing techniques and their subsequent performance characteristics analysed. A material identified in this way was SmCoVCu, producing 42 kl/m^3. One of the challenges they had, demonstrated through a unique video, was the Sm boiling off during sintering, leaving the grain boundary and reducing the performance. This was modified by processing at 1,000 ^oC rather than 1,150 ^oC. Currently the material has a Br of around 0.7 T and a 0.6 THc.

Our final talk for the day came all the way from America via Skype. Mark Senti of AML promoted the use of their unique and novel MagWire for use in motors with his talk *PM-Wire: A New Permanent Magnet (PM) Technology.* This was one of the most eagerly awaited talks as the technology is so shrouded in mystery. Sadly the detail so many were hoping for was kept under lock and key, but enough nuggets of information seeped through to satisfy

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the crowd. Having spoken to many in the audience later that night there were at least 4 companies keen to get an NDA with AML and look at using the material in their applications. The technology was driven from a funding round with NASA, initially looking at superconducting wire and elements of this manufacturing process have been adopted to NdFeB. It's not the strongest material out there at 38 MGOe but the versatility and application of magnetic fields during the manufacturing process make it ideal for Halbach style Surface mount rotors.

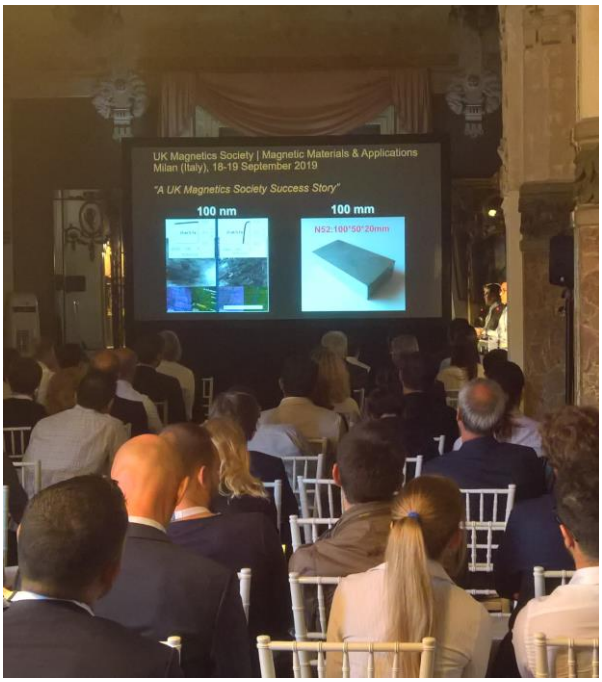
Not content with providing an excellent venue, LE also sponsored a drinks reception and evening meal, both with a fabulous local menu. The full Italian aperitivo led some delegates to believe this was dinner, only to find they had a full meal to sit down to after the reception! Jeremy Tompkins briefly opened the dinner by thanking the delegates for attending, the speakers for presenting, and, after congratulating LE on their 60th anniversary, also thanked them for providing such excellent and propitious surroundings.

Impressions from the first day were excellent all round and people were certainly looking forward to day 2!

Day 2 began with a presentation from Chris Riley, Group Magnetics Engineer at Bunting Magnetics Europe Ltd. Chris presented on the use of *Post Assembly of Halbach PM Rotors*. The post-assembly approach provides many advantages including reduction of health and safety implications of handling magnetised materials, reduced assembly time, simplification of operations like machining, grinding and balancing and facilitation of high-performance composite over-banding materials previously limited by the high cure temperature required which degrades magnetisation. Of course, these benefits come at a cost in the form of designing an ideal field pattern and associated fixture. Chris detailed the challenges of achieving a high field to saturate the magnet material while minimising energy expenditure. Sophisticated numerical tools including FEA are used to predict the required field, design the appropriate fixture, and compare theoretical and practical performance. Innovative mechanical stepping allows rotors of various lengths to be magnetised with a single fixture. A key lesson from the talk is that post-assembly magnetisation can bring a wide range of cost reducing benefits, but designers must consult magnetics engineers as soon as possible in the design cycle to take full advantage.

The second speaker of the day, titled *A UK Magnetics Society Success Story* was Rupert Cruise of Magway. Urbanisation is a significant global trend, for example European cities are home to over 70% of the population and account for 85% of GDP. As population densities increase the need to transport packages and goods increases counter to the need to reduce congestion and pollution. Magway aim to solve this logistical issue using a stream of standardised autonomous vehicles each with a payload of 32 kg driven by Permanent Magnet Linear Synchronous Motors. The rail guided vehicles are housed within a 0.9 m

diameter pipe-like structure making them invulnerable to adverse weather conditions while the sophisticated control and propulsion system allow up to 15 m/s speeds with 15 ms separation and the ability to travel vertically if needed. Rupert is working with InnovateUK and private investors to make the technology a reality. It's a Society success story in that some of the project's key collaborators began talking at a previous Society MMA event hosted by Vacuumschmelze in Hanau.



Rupert Cruise delivers his talk on Magway's revolutionary approach to logistics.

Matteo Pistaffa of LE delivered a talk on *Shielding Effects During Permanent Magnets Magnetisation Process*, i.e. reduction of the magnetic field during the magnetisation process. The predominant shielding mechanisms are reflection or diversion of the field where the skin depth of the material dictated by the magnetic permeability, electrical conductivity and frequency of the applied field can be exploited to control the phenomenon. In particular, this talk focused on the positive use of shields in magnetising fixtures to enhance the spatial distribution of the field and improve efficiency as well as analysing the parasitic shielding effect of intrinsic components such as the magnetic circuit of a loud speaker where the effective shield must be penetrated by the field during the magnetisation process.

In *Eddy Current Reduction by Snake Line*, our fourth speaker, Patrick Aeschlimann from BOMATEC, introduced the audience to a new patented production process designed to reduce the eddy current losses in permanent magnets composed of NdFeB and SmCo materials. Large blocks of PM material subject to time varying magnetic fields give rise to internally generated eddy currents which manifest as loss and internal heating. In high performance applications this is reduced by laminating or segmenting the magnets, i.e cutting into sections, applying a glass bead glue and re-assembling to increase the effective electrical resistivity of the material. However, this practise incurs significant processing and labour costs. Bomatec's Snake Line approach is to use Electrical Discharge Machining (EDM) to cut a specific thin meandering line through the PM material, maintaining a single piece of PM and then filling the void to yield an assembly-free laminated PM exhibiting significant overall cost reduction. The technology has great potential but the loss in PM volume and limitation on the dimensions of the cut lines must be accounted for at design time.

Martin Krengel from Wilo SE gave the next talk, *Alternative Magnet Production Way by Hot Pressing - A Pump Manufacturer Becomes a Magnet Producer*, a different angle on magnet manufacturing, where production is done in house rather than buying magnets in. Although constrained by commercial considerations, Martin's interesting talk covered his history with the same organisation through its changes: Thyssen Edelstahlwerke Magnetfabrik Dortmund, Thyssen Magnettechnik in Tridelta, and finally Wilo SE, working on magnetic materials, corrosion protection for NdFeB, SmCo production, and currently in house NdFeB production using a hot press process. He explained the advantages and disadvantages of the hot pressing process compared to sintering, and gave an outlook on the possibilities that the process could still offer.

Spin Applicazioni Magnetiche's Alessandro Tassi spoke on *Computer Simulation Techniques: Evolution and Perspectives*, giving a short history of numerical and computational simulation, highglighting current capabilities, and predicting that

- Multidisciplinary interaction between different disciplines will improve, driven by better interfaces, and more informed demand from users;
- Optimisation algorithms will become more reliable and easier to set;
- Computation time will fall, due to multicore and multiprocessor computers allowing cheaper distributed computation;

- Improved and increased memory will get cheaper, assisting 3D modelling and multisciplinary analysis;
- Material knowledge such as fatigue effects, magnetic losses, laminated / composite materials properties will become more prevalent in CAED packages;
- and finally, that we may soon be using meshless FEA.

Our penultimate talk of the day, *Extraction and Recycling of Rare Earth Magnets: Magnetic Materials Group Pilot Plant Development*, was delivered by Dr Lydia Pickering, a research fellow in the School of Metallurgy and Materials, University of Birmingham, UK. Increased demand for PM material coupled with geopolitical sensitivity of raw material costs is driving the desire for a more sustainable circular economy in which PM material is recovered from end-user devices and recycled. Lydia introduced the audience to the SUSMAGPRO (Sustainable Recovery, Reprocessing and Reuse of Rare-Earth Magnetic in a Circular Economy) project which aims to identify, separate, reprocess and reuse NdFeB magnets at a pilot scale across Europe. The pilot focused on the reprocessing of Hard Disk Drives (HDDs) where a robotic system was used to automatically identify the appropriate PM rich region of HDDs and crop this section into a hopper in preparation for further processing. Techniques such as hydrogen decrepitation were then used to simultaneously demagnetise and reduce the PM material to a powder form. A significant challenge in the process is removing the PM protective coating, often nickel based. The pilot is set to achieve 5 kg of useable material from 200 HDDs, and if successful, will serve as an important demonstration and first step in achieving a sustainable, circular model for future materials use.

As befitted the company's 60th anniversary, Andrea del Prete, LE's VP of Magnetic Technology, closed the technical talks with an overview of *Laboratorio Elettrofisico's 60 Years' Experience in Magnetic Measurements*, outlining the company's history, its development and current capabilities and products. In 1958, Centro Magneti Permanenti started producing hard ferrites, and LE was established in 1959 to provide the necessary magnetic measurements. Andrea gave a thorough overview of LE's range of magnetising and measurement equipment across many material types including hard, semi-hard, feeble, and soft materials. He concluded by giving his thoughts on future material challenges and requirements:

Hard Materials

- PM with higher operating temperatures (150-200 °C)
- Less RE and Dy
- PM motors with higher specific power
- Non-regular shapes
- Smaller and bigger parts
- Higher and lower operating temperatures
- Control of magnets in the final assembly
- Possibility to measure higher coercivity grades
- Losses in hard materials

Soft Materials

- Higher permeability
- Lower losses
- Smaller thickness
- Non-regular shapes
- Higher and lower operating temperatures
- Different excitation waveform conditions
- Better correlation between different methods
- Better accuracy on the losses

Following the close of the seminar at the Villa Ida Lampugnani, delegates were treated to a guided tour of LE's Milan facilities. After viewing design and production facilities from a discreet distance, the visit culminated in an unexpected but very welcome impromptu drinks reception on the top floor of LE's newly expanded facility.

Departing the site, delegates were returned to their accommodation, and most headed off at that point. 20 or so dedicated souls continued networking through an evening walking tour of Milan guided by Follow Mi Around, taking in the Castello Sforzesco, the L.O.V.E. statue in Piazza Affari, Galleria Vittorio Emanuele II, Duomo di Milano, and ending with a light dinner in the Navigli district. As the light faded, conversation flowed as well as the beer and wine, some of it even work related.

We are most grateful to our sponsors for an excellent and most useful event, only made possible by their generous support: BCMaterials, and our hosts and long time members of the Society, Laboratorio Elettrofisicio. This event and the other activities of the Society would not have been possible without the additional support of companies like our Society Sponsor, Bunting Magnetics.

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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