Institution: University of Sheffield

Unit of Assessment: 13B - Electrical and Electronic Engineering, Metallurgy and Materials: **Electronic and Electrical Engineering**

Title of case study: International commercial impact from the creation of the spin-out company Magnomatics Ltd.

1. Summary of the impact

Research in the Department of Electronic & Electrical Engineering at the University of Sheffield has generated economic impact through the creation of a spinout company, Magnomatics Ltd, commercialising high performance electric drives, in particular those employing magnetic gearing technologies. Magnomatics employs 35 full-time staff, had a turnover of £1.4M for the year 2012, and its technologies are now being developed for applications in utility scale wind turbines, hybrid vehicles and marine propulsion.

2. Underpinning research

Mechanical gearboxes are used extensively to match the operating speed of prime-movers to the requirements of their loads, both for increasing and decreasing the rotational speed. However, although high system torque densities can then be achieved, gearboxes usually require lubrication and cooling, whilst noise, vibration and reliability can be significant issues. Magnetic gears can offer several advantages, such as, reduced acoustic noise and vibration, reduced maintenance and improved reliability, inherent overload protection and physical isolation between input and output shafts. Despite these advantages magnetic gear topologies have exhibited very low torque transmission densities which severely restricted the scope of their applications.

In 2001, Professor Kais Atallah (University of Sheffield, since 1994) proposed a magnetic gear topology, with a theoretical torque transmission density in excess of 100kNm/m^3, which is at least an order of magnitude higher than the torque density of magnetic gear topologies proposed previously [R1]. Following an EPSRC funded 12-month feasibility study (GR/R46519/01), in 2002, together with Dr Stuart Calverley (Research Associate), he realised a demonstrator magnetic gear which confirmed the theory [R2]. During a follow-up EPSRC funded project (GR/S70685/01), which started in August 2004, Atallah proposed a novel method of integrating a magnetic gear with a brushless permanent magnet machine to realise a very torque dense 'pseudo' direct-drive machine [R3], a novel harmonic magnetic gear, and a linear version of the magnetic gear [R4]. Together with Dr Jan Rens (Research Associate), he produced the first demonstrator 'pseudo' direct-drive-drive machine. For both EPSRC funded projects Atallah was the PI and the research was rated as internationally leading.

Although various ways of integrating a permanent machine with a magnetic gear exist, the proposed technique enables a permanent magnet machine and a magnetic gear to be mechanically as well as magnetically integrated, hence, optimising the utilisation of the permanent magnet material and simplifying the mechanical construction. The proposed and demonstrated 'pseudo' direct-drive electrical machine exhibited a torque density higher than that of the state-of-the-art transverse permanent magnet machine, with the added benefit of a much improved power factor, i.e. more than 0.9 for the 'pseudo' direct-drive electrical machine compared to a reported maximum of ~0.5 for the transverse flux machine. Inherently, the low power factor of transverse flux machines, which were proposed in 1980s, has been the main obstacle in the way of their adoption for many applications where torque density is a very important characteristic, such as ship propulsion.

Although the 'pseudo' direct drive has been the main technology being commercialised by Magnomatics Ltd, it is certainly not the only one. Atallah has also researched and produced a novel power-split device based on the magnetic gearing topology described above, and which can be operated as a magnetic Continuously Variable Transmission (CVT) [R6].

3. References to the research

The underpinning research, which lead to the incorporation of Magnomatics Ltd., was published in the following: (the best references are in bold)

R1. **K. Atallah, D. Howe, "A novel high-performance magnetic gear", IEEE Transactions on Magnetics, Vol. 37, No. 4, pp. 2844-2846, 2001. doi: 10.1109/20.951324**

R2. **K. Atallah, S. D. Calverley, D. Howe, "Design, analysis and realisation of a high performance magnetic gear", IEE Proceedings - Electric Power Applications, Vol. 151, pp. 135-143, 2004. DOI: doi: 10.1049/ip-epa:20040224**

R3. **K. Atallah, J. Rens, S. Mezani, D. Howe "A Novel 'pseudo' direct-drive brushless permanent magnet machine", IEEE Transactions on Magnetics, Vol. 44, No. 11, pp. 4349-4352, 2008. doi: 10.1109/TMAG.2008.2001509**

R4. J. Rens, K. Atallah, S. D. Calverley and D. Howe, "A Novel magnetic harmonic gear", IEEE Transactions on Industry Applications, Vol. 46, No. 1, pp. 206 – 212, 2010. doi: 10.1109/TIA.2009.2036507

R5. R. C. Holehouse, K. Atallah and J. Wang, "Design and realisation of a linear magnetic gear", IEEE Transactions on Magnetics, Vo. 47, No. 10, pp. 4171-4174, 2011. doi: 10.1109/TMAG.2011.2157101

R6. K. Atallah, J. Wang, S. D. Calverley and S. Duggan, "Design and operation of a magnetic continuously variable transmission ", IEEE Transactions on Industry Applications, Vol. 48, No. 4, pp. 1288 – 1295, 2012. doi: 10.1109/TIA.2012.2199451

4. Details of the impact

In July 2006, Magnomatics Ltd was spun-out from the University of Sheffield in order to commercialise the high performance electric drives employing magnetic gearing arising from the research at Sheffield. Magnomatics is now recognised as a world leader in magnetic gearing-based products and services, and has a worldwide customer base, mostly large multinationals and governments.

Magnomatics Ltd :

- Currently employs 35 full-time staff.
- Had a turnover of £1.4M for the year 2012.
- Had a total investment of £3.4M, with a latest investment of £2.5M was completed on 16th November 2012. The purpose of the investment is to enable Magnomatics Ltd to complete the development of its technology for the electric/hybrid vehicle markets.
- Has 21 patent families that stem from the underpinning research, with 6 granted and the rest in application.
- Was selected as a New Energy Pioneer at the 2010 Bloomberg New Energy Finance Summit.
- Won the prestigious 2011 Northern Defence Industries (NDI) Innovation and Technology Award [S1].

In 2008, Magnomatics Ltd led a consortium [S2], which included Volvo, for the development of 'pseudo' direct-drive electrical machines for applications in trucks, buses and construction vehicles.

In 2009, Magnomatics Ltd won contracts, totalling ~£1M in 2009 [S3-S5], from the Ministry of Defence's (MOD) Programmes and Technology Group for the design, manufacture and testing of a scale prototype of a 300kW naval 'pseudo' direct-drive machine that will de-risk production of a 15MW full size naval propulsion machine. The high torque density, high efficiency and the and

inherently lower acoustic noise emissions makes the 'pseudo' direct-drive machine an attractive alternative for military and civilian ship propulsion.

In 2011, results from a first prototype magnetic CVT of its kind attracted the attention of major OEMs, leading to TSB funded projects worth more than £0.5M for Magnomatics Ltd [S6,S7] for the development of a magnetic CVT for hybrid passenger vehicles in collaboration with Ford Motor Company and another for larger vehicles with Caterpillar Engines. The adoption of a magnetic CVT enables the realisation of hybrid drive-trains with similar architectures and functionalities as the Synergy Drive® employed by Toyota on its hybrid vehicles, while potentially circumventing the Intellectual Property owned by Toyota.

As stated in the FP7 Work Programme 2012, for wind turbine applications, the 'pseudo' direct-drive is now recognised as an innovation which can have a major impact on large wind turbine head mass. In theme 5, Energy [S8], the 'pseudo' direct-drive is specifically mentioned as one of the major innovations which should be investigated for future 10MW-20MW wind turbines. Magnomatics Ltd, together with Siemens Wind, Ramboll Group, Gamesa and other academic partners which include the University of Sheffield are currently partners on an EU funded project, investigating the feasibility and design of light weight 10MW-20MW future wind turbines.

In 2013, Magnomatics Ltd has received a £1M grant from the Regional Growth Fund, in order to further the development of its magnetic transmission systems, such as the magnetic CVT and the high-torque PDD, and create 41 new jobs by 2015 [S9].

5. Sources to corroborate the impact

S1. Managing Director of Magnomatics can corroborate the details of the company.

S2. http://www.theengineer.co.uk/news/magnomatics-top-gear/308343.article

To corroborate MOD contracts:

S3. http://www.theengineer.co.uk/news/magnomatics-signs-defence-deal/312859.article

S4. http://www.thestar.co.uk/news/business/warship_deal_for_university_spin_out_1_295424

S5. http://www.maritimejournal.com/features101/power-and-propulsion/magnetic-gearing-enables-compact-electric-propulsion-motors

To corroborate TSB contract and participants:

S6. http://www.themanufacturer.com/articles/magnomatics-to-work-with-ford-and-caterpillar/

S7. http://www.yorkshirepost.co.uk/business/business-news/contracts-put-power-into-magnomatics-1-3991045

To corroborate the pseudo direct drive innovation:

S8. FP7 Work Programme 2012, Theme 5, Energy, page 12.

To corroborate the Regional Growth Fund grant:

S9. http://shrewddnews.wordpress.com/2013/08/12/magnomatics-to-use-1m-rgf-grant-to-generate-41-new-jobs/