Institution: City University London

Unit of Assessment: 15 General Engineering

Title of case study: Transforming the energy efficiency of gas compressors and expanders across the world

1. Summary of the impact

City University London's patented rack generation mechanism, the '"N" rotor profile', offers substantial improvements on the rotary screw compressors widely used in industry at present. It allows for an increase in compressor capacity and makes compressors more energy efficient. Significantly, it can be easily retrofitted to existing compressors, thereby delivering immediate benefit. The mechanism has already been licensed to 27 major manufacturers around the world, resulting in savings of 0.1% of global electricity consumption and an equivalent reduction in global CO_2 emissions. City academic staff have worked with an existing firm (Howden Compressors Ltd) to raise funds and train researchers for the development of this technology. In addition, a new spin-out company (Heliex Power Ltd) has been formed to build on research developed since 2009.
Important examples of the impact include:

- An increase in annual turnover at Howden Compressors Ltd. from £15M in 2009 to £39M in 2011 and a 40 % increase in the number of staff employed.
- The spin-out company Heliex Power Ltd is valued at £15M and has employed an additional 23 people following investment of £7M from BP Alternative Energy and ESB Novusmodus. A further £3M will have been invested by the end of November 2013. Heliex has been named in the 2013 Global Cleantech 100 list.
- An estimated reduction in carbon dioxide emissions worldwide from energy efficiency improvements totalling 30 Mt (0.1% of total emissions).

This research has enabled companies that operate worldwide in air compression, refrigeration, air conditioning, oil, gas and process industries to improve their economic and environmental performance in response to demanding governmental demands.

2. Underpinning research

Twin screw compressors are positive displacement rotary machines used in air compression, refrigeration, air conditioning, oil, gas and process industries. They represent approximately 80% of the millions of industrial positive displacement compressors produced globally each year, A derivative of the concept operates as an expander to generate power. Compressors consume approximately 15% of the world's electricity, so an improvement in their efficiency, however slight, can have a significant impact on the economy and the environment.

The research on these machines at City began in 1993 with a grant from the Science and Engineering Research Council awarded to Professor Ian Smith (a member of academic staff City since 1962) to study power generation from low grade heat sources, using twin screw machines.

Based on his expertise in modelling screw compressors, Professor Nikola Stosic (a member of academic staff since 1995) developed a software package called SCORPATH (Screw Compressor Rotor Profiling and Thermodynamics). This work led to a full understanding of the processes at work in screw expander machines, which can generate power from low grade heat sources such as the expansion of liquid and vapour.

With support from the Royal Academy of Engineering and the rotor manufacturer Holroyd, Professors Stosic and Smith established the 'Centre for Positive Displacement Compressor Technology' at City in 1996, with the aim of assisting industry in the design and development of screw machines. Backed by the Institution of Mechanical Engineers (IMechE), City now hosts a biennial international conference on Compressors and their Systems which has become a major meeting point for the compressor industry.

In 1996, building on his earlier work on the mathematical modelling of gears, Professor Stosic

developed and patented a new type of rotor profile (the "N" rotor profile) that was fundamentally superior to existing types. It increased the efficiency of screw compressors by at least 8%, reduced noise generation and made lubrication requirements less onerous. The "N" rotor profile was consequently used extensively in industry and the income received from this and other work for industry was used to extend research at the University on screw compressors.

Professor Ahmed Kovacevic joined City in 1998 and by 2003 had pioneered the application of Computational Fluid Dynamics (CFD) to analyse screw compressors. His breakthroughs in this field were later validated experimentally by the use of Laser Doppler Velocimetry. Kovacevic created a software suite for the analysis, called SCORG (Screw Compressor Rotor Grid Generation), which is now widely used by many academic and industrial institutions. It has contributed to better understanding of phenomena such as leakage flows, noise generation in compressor ports and the effects of thermal and pressure loads on compressor elements.

Integrating SCORG with SCORPATH, Professor Kovacevic went on to create a new software suite called DISCO© (Design Integration for Screw Compressors) which offers CAD tools with advanced CFD analysis. It has become the new industry standard in this field of engineering.

In 2008 Professor Kovacevic applied his experience of designing screw machines to form and train a team of 15 researchers at Howden Compressors Ltd. in Glasgow. He raised around £6.5M of industrial funds within the company to establish improved Design Principles for Screw Compressors, boosting company turnover, profit and employment.

In 2009, research on a new system for the recovery of power from industrial processes and engine exhaust gases, using the expansion of wet steam in screw machines, led to the formation of the spin-out company Heliex Power Ltd.

3. References to the research

1. Kovacevic A., Stosic N., Smith I.K., Mujic E. & Gueratto D. (2011). Extending the Role of Computational Fluid Dynamics in Screw Machines, *Proc. IMechE, Part E: J. Process Mechanical Engineering*, 225(83) 10.1177/ 0954408910397586 **Winner of the IMechE Moss Prize 2011 for the best paper**

2. Mujic E., Kovacevic A., Stosic N. & Smith I.K. (2011). Noise generation and suppression in twin screw compressors *Proc. IMechE, Part E: J. Process Mechanical Engineering,* 225(2) 127-148 10.1177/1464419311403875 **Most read paper in JPME in February 2013**

3. Kovacevic A., Fairbairn J. & Fain N. (2012) *Technical-commercial interface - a baseline for successful new product development*, International Design Conference - DESIGN 2012, Dubrovnik, Croatia, May 21 - 24 2012. http://www.designsociety.org/publication/31970/technical-commercial_interface-a_baseline_for_successful_new_product_development

4. Smith I.K., Stosic N., Kovacevic A. & Mujic E. (2011). Steam as the working fluid for power recovery from exhaust gases by means of screw expanders *Proc. IMechE, Part E: J. Process Mechanical Engineering*, 225(2), 117-126 10.1177/2041300910393429 **Winner of the IMechE Ludwig Mond Prize for 2011**

5. Stosic N., Smith I.K., Kovacevic A. & Mujic E. (2011). Review of Mathematical Models in Performance Calculation of Screw Compressors *Int. J. Fluid Machinery and Systems,* 4(2) 10.5293/IJFMS.2011.4.2.271

6. Stosic N., Smith I.K., Kovacevic A. & Mujic E. (2011). Geometry of screw compressor rotors and their tools *Journal of Zhejiang University-SCIENCE A, Applied Physics & Engineering,* 12(4), 310-326, 10.1631/jzus.A1000393

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Prize (output 1) was awarded for the best paper on a process industries mechanical engineering subject published by the Institution in the previous year. The Ludwig Mond Prize (output 4) was awarded for the best contribution made during the previous year to the progress of mechanical engineering of interest to the Chemical Industry.

4. Details of the impact

City's Compressors Grouphas developed a worldwide reputation. It has advised or assisted 68 organisations in 26 countries on compressor and expander design.[1] It is believed that more than half the world's screw compressors, currently manufactured, contain our patented "N" profile rotors.

(1) <u>Economic Impacts</u>

(a) Profiling and Design of Screw Compressors

Our 1996 "N" rotor profile patent (GB9610289) has allowed the design of screw machines that are cheaper and more efficient, with a broader range of applications, than earlier technologies. In many cases, the Group designed, built and tested machines in order to validate their predicted performance. In others licensees, after training at City, have used this profile to design new products in conjunction with technical advice from academic staff. It has been licensed to 27 manufacturers, including world-leading companies. Three examples of its use since 2008 are listed below:

- **Holroyd**, the original sponsors of our Compressor Centre, were able to penetrate the Chinese market in the face of strong competition from foreign manufacturers. This led to their acquisition by the CQME Group, valued at $1 billion, in June 2010.[2]
- **Howden Compressors Ltd** is the major compressor manufacturer in the UK (www.howden.com). The use of our "N" rotor profile and new design principles allowed the company to secure the single largest contract in its history (£14M), raise its turnover, from £15M in 2009 to £39M in 2011 and expand its staff by 40%. Income to the University resulting from work with Howden has totalled over £1M to date.[3]
- **RotorComp**, a major German manufacturer, developed a new family of air compressors, also based on our "N" rotor profile, and consequently increased their sales from 19,000 units to 50,000 units per annum between 2008 and 2010.

(b) Screw Expanders for Power Recovery from Low Grade Heat

A market survey by BP Alternative Energy International on the use of City's concepts for power recovery found that the potential world market was in excess of $5 billion per annum. Two examples on the use of these concepts in practice are given below:

● Industrial partnership with ELECTRATHERM
ELECTRATHERM (www.electratherm.com) is a US manufacturer of small scale Organic Rankine Cycle Systems (ORC) for power generation from low grade heat sources. In 2006 they were granted a licence to use the City expander technology for power recovery in their "Green Machine". The company has since received investment of more than $30M.

Since 2011, more than 50 "Green Machine" systems which utilise expanders manufactured by Howden Compressors Ltd in the UK have been installed in the field. These recently reached a cumulative 87,000 hours of operation, thereby generating approximately 300 MWh of electrical energy so far. The demand for such machines is rapidly rising.

● New spin-out: HELIEX Power Ltd
HELIEX Power Limited (www.heliexpower.com) is a spin-out company from City University London established in 2009 to commercialise innovative steam screw expander technology to utilise waste energy from industrial steam.

BP Alternative Energy International made an initial investment of £2M at the end of 2010 to get HELIEX started.[2] A further £5M has since been raised from BP and Greencoat Capital, the investment arm of the Electricity Supply Board of Ireland. A further £3M investment from these companies will have been made by the end of November 2013. Pre-production machines have been successfully tested and the first commercial machines have been installed, including one in a steelworks in Italy. Currently the company is valued at £15M and employs 23 people. Heliex has established a factory at East Kilbride near Glasgow with a capacity of 2,000 steam screw expander generator sets per year and production is under way. The company has also built a test and development centre which incorporates 160 and 600kW dynamometers and a 0.5MW connection to the national grid. Each generator set sells for between £110,000 and £240,000 depending on size. A European distributor network is being established and the company is exploring joint ventures in China (market for 1M units) and India.[6] Heliex has been named in the 2013 Global Cleantech 100 list.[7]

(2) Impacts on the environment

According to the International Energy Agency, approximately 15% of global electrical energy is consumed by motors driving compressors, while approximately 80% of all industrial compressors are of the twin screw type and would benefit from the fitting of our more efficient 'N' rotor design.[8]

Such retrofitting would improve the energy efficiency of these widely used devices by up to 8%, resulting in a reduction in global power consumption of at least 0.1% and an equivalent reduction in global CO_2 emissions. Based on Enerdata's *Global Energy Statistical Yearbook 2013*, this accounts for around 30 Mega Tons (Mt) of CO_2 per annum.[9]

(3) Impacts on practitioners and professional services

To maximise uptake of our analytical software, we have run training courses for engineers and designers in more than 30 organisations over the past few years.

For example, our work with Gardner Denver, the world's largest manufacturer of air screw compressors, has ensured that the firm now exclusively use our "N" profile rotors and our DISCO© and SCORPATH software. Dr Elvedin Mujic, a former PhD student in the Group, is now a leading researcher in Bitzer, a major German manufacturer of refrigeration compressors.

City organises a biennial International conference on 'Compressors and their Systems' which is backed by the IMechE. It is the main meeting point of leading engineers and managers from more than 100 major world compressor manufacturers. This serves as a forum for dissemination of results achieved at City and has had a big impact on industry since its inception in 1999 (http://www.city.ac.uk/compressorsconference).[10]

5. Sources to corroborate the impact

1) List of selected major research and consultancy projects of the Compressor Centre available on request
2) Holroyd, Head of R&D - www.holroyd.com
3) Howden, CEO Compressor Division – www.howden.com
4) http://electratherm.com/
5) Applications of screw expanders video: **BP Ventures – Heliex** http://vimeo.com/36842177
6) HeliexPower, CEO – www.heliexpower.com
7) (http://www.cleantech.com/global100/global-cleantech-100/)
8) http://www.iea.org/publications/freepublications/publication/EE_for_ElectricSystems.pdf
9) http://yearbook.enerdata.net/
10) Biennial International conference on 'Compressors and their Systems' (www.city.ac.uk/compressors-conference-2011)