Institution: City, University of London

Unit of Assessment: Engineering

Title of case study: Innovating and maximising screw compressor performance

Period when the underpinning research was undertaken: 2000 – ongoing

Details of staff conducting the underpinning research from the submitting unit:

Name(s):	Role(s) (e.g. job title):	Period(s) employed by submitting HEI:
Professor Ahmed Kovacevic	Howden/Royal Academy of Engineering Research Chair in Compressor Technology	1998 - present

Period when the claimed impact occurred: August 2013 - ongoing

Is this case study continued from a case study submitted in 2014? N

1. Summary of the impact

The SCORG software was developed from research carried out at the Centre for Compressor Technology, City, University of London. It allows critical analysis and design of positive displacement compressors, expanders and pumps by use of Computational Fluid Dynamics (CFD) and lower order models. [text removed for publication]. The software has boosted productivity and profitability of screw compressor manufacturers globally. Companies such as Howden, UK, Kirloskar, India and Mayekawa, Japan have utilised SCORG in introducing new superior products in the market.

2. Underpinning research

Screw compressors, expanders, extruders, blowers, pumps and motors are positive displacement machines commonly used in industrial refrigeration, air conditioning, process gas handling and variety of liquid, multiphase and vacuum pump applications. It is estimated that 20% of world energy is used for various means of fluid handling. In early 2000 Prof Kovacevic recognised that the growing demand for these machines and requirements for reducing their impact on environment could not be realised with tools and methods used at that time by the majority of industries. To change this, advanced tools for 3D modelling such as Computational Fluid Dynamics (CFD) are required which were not available for such complex moving and stretching flow domains as in screw machines.

Since 2000, through working on modelling, design and development of screw machines, Kovacevic devised a practical, affordable solution to the problem by developing (i) a theoretical understanding of decomposition of complex domains in subdomains by use of rack surface as a unique divider between the flow domains of the rotors **[3.1]** and (ii) software algorithms capable of calculating 2D transverse cross sections along the rotor domains for joining them in the full 3D numerical mesh, rapidly using only a standard PC or laptop **[3.2]**. The research then addressed how these subdomains could be mapped using algebraic grid generation procedures, boundary adaptation, orthogonalisation and smoothing. Other requirements for fast and reliable software were also considered.

The breakthroughs achieved in this field were later validated experimentally by the use of Laser Doppler Velocimetry. A software suite **SCORG (Screw Compressor Rotor Grid Generation)** was developed based on that research for grid generation and analysis of screw machines. It is now used extensively by academic and industrial institutions across the world. SCORG has become the new industry standard in this engineering field.

The theoretical understanding developed in the course of the research, and the algorithms for grid generation of 3D geometry alongside case studies on its success were set out in a book first published in 2006 **[3.3].**

Since 2010 the research has focussed on how the software could be used, not only in modelling existing systems, but also for exploring ideas for novel machines such as variable geometry rotor machines and internally geared machines **[3.4]**.

The research then continued in exploring additional options for detail exploration of physics within a screw machine, in particular the effect of conjugate heat transfer in the leakage gaps **[3.5]**. In addition, the multi-chamber thermodynamic model was developed and implemented in SCORG to allow its thermodynamic results to be used for analysis of flow and deformations.

3. References to the research

3.1 A. Kovacevic, N. Stosic, I. K. Smith, '*Three-Dimensional Numerical Analysis of Screw Compressor Performance*', Journal of Computational Methods in Sciences and Engineering, vol. 3, no. 2, 2003, pp. 259- 284

3.2 A. Kovacevic, *'Boundary Adaptation in Grid Generation for CFD Analysis of Screw Compressors*', International Journal for Numerical Methods in Engineering, 2005. Vol 64: 401-426

3.3 A. Kovacevic, N. Stosic, I.K. Smith, '*Screw Compressor Three Dimensional Computational Fluid Dynamics and Fluid Solid Interaction'*, Springer, 2006, ISBN 3-540-36302-5

3.4 S. Rane, **A. Kovacevic**, N. Stosic, M. Kethidi, '*Deforming grid generation and CFD analysis of variable geometry screw compressors'*, Computers and Fluids, 99, p. 124–141., 2014

3.5 A. Kovacevic, S. Rane, *Algebraic generation of single domain computational grid for twin screw machines Part II – Validation*, *Advances in Engineering Software*, 107, pp., 2017, doi: 10.1016/j.advengsoft.2017.03.001

4. Details of the impact

Spin Out: PDM Analysis

The creation of SCORG software and its immense potential led to the establishment of PDM Analysis Ltd (PDM), a City, University of London spin-out with the responsibility of commercialising the software.[text removed for publication]. [5.1]. PDM has established global partnerships with leading companies in the field of CAE software, such as Simerics (US), Gamma Technologies (US) and through them distribution agreements with 80/20 Engineering Ltd (UK), Hi-key Technology Corporation Ltd (CH) and Wave Front Co. (JP). Simerics has been using SCORG with one of its two primary products, Simerics-MP+ and has integrated the software with their own CFD tool Pumplinx [5.2]. Clients for the final suite in its various forms include DM8 Composites, HSMarine, Hyundai, Dasault and others.

Likewise, Gamma Technology (GT) has created a seamless integration between SCORG and their leading CAE product GT-SUITE. The partnership offers customers reliable advanced simulation capabilities for screw machines based on the complementary strengths of each tool. [5.3] This partnership has allowed the software to reach clients such Mercedes Benz India, Borg Warner, GM Powertrain and others. GT have confirmed that thanks to this partnership they have seen an increasing number of screw machine OEMs (ranging from air compression to air conditioning) adopt simulations via the combined use of GT-Suite and SCORG [5.3]. Use of simulation leads to reduction in the number of design iterations during product development, reducing physical testing, and shortening the product time to market. The increased efficiency in the design process also helps reduce greenhouse gas emissions by curtailing electric energy consumption (current estimate is that 25% of electricity usage in US during summer months is related to compression) [5.3]

Industry Partners: Howden Compressor Ltd, Scotland, UK

Howden is a world-class engineering company with 6,000 employees in 27 countries and is undergoing a period of significant business growth. It provides high-quality air and gas handling products and services to the power, oil & gas, mining and petrochemical industries, with an estimated annual revenue of $351M. Howden has a long-established partnership with City, University of London, which has been instrumental in fostering a decade of rejuvenated research and development within the company [5.4]. During the current period (2014-20) Howden utilised SCORG in the development of the world's largest oil injected twin screw compressor with 580mm diameter rotors (2016). Digital prototyping with SCORG

provided the high level of confidence required to make the significant investment in a physical prototype. This successfully validated the compressor design. By avoiding the need for extensive design iteration and repeat testing, the prototype could be used in commercial projects [5.4].

Howden also utilised SCORG in 2017, during the key phase of the design of a new range of oil free compressor. This work utilised the fast, efficient chamber model and geometry editing features available in SCORG to study a wide range of designs [5.4]. The project,[text removed for publication], led to the launch of the new range of compressors, which aims at increasing its share on the global oil-free screw compressor market by 2021 [5.5] Howden continues to utilise SCORG in product development and education, and in their R&D department when providing critical business support; this can range anywhere from contract proposals through to contract testing [5.4].Thanks to this long standing collaboration Prof. Kovacevic has been named Howden Chair in Engineering Design and Compressor Technology since 2008 and in 2020 he became the Howden / Royal Academy of Engineering Research Chair in Compressor Technology [5.6]

Global Impact: Kirloskar (India) and Mayekawa (Japan)

The quality of the research and the software has enabled SCORG's impact to extend beyond UK borders. Two major international companies operating in the compressor industry have utilised SCORG with positive results. Kirloskar Pneumatic Company Limited (KPCL) has collaborated with Prof Kovacevic and his team since 2015 in a two-phase project. Phase 1 (2016-2019) saw the successful development of a new range of oil injected screw compressors, as well as the creation of a team of dedicated engineers within the KPCL [5.7]. KPCL proceeded with the investment of over £500K to phase 2 (2019-2022), with the aim of developing the best-in-class screw compressors and opening new markets. [5.7].

Similarly, Mayekawa Manufacturing approached the university in 2018 based on the strength of the research generated by the Compressor Centre and Prof Kovacevic's team. . [text removed for publication]. [5.8]

Both companies have utilised SCORG extensively and have experienced significant positive impact in their development processes. KPLC found that on average 1-2 months of the experimental validation for a design change were saved, along with corresponding savings in man-hour rates and flexible modification costs [5.7]. Mayekawa, found that SCORG helped the company to better map, analyse and understand the processes withing the screw compressor and allowed reducing time-consuming experimentation [5.8]. [text removed for publication]. [5.8].

Continued Industry Engagement and Commercialisation

The success of the Centre and SCORG continues to grow, attracting further interest, engagement, and collaboration with industry. The main vehicle for this is the biannual "International Conference on Compressors and their Systems", organised by City, University of London and the Compressor Centre. Its 11th iteration, held in 2019, attracted more than 250 attendees from 24 countries, led to the publication of 94 technical papers and hosted 10 exhibitors [5.9] The conference is of such importance to the compressor industry that exhibitors such as Vert Rotors UK Ltd use it as a platform to announce new products [5.10]. SCORG itself continues to attract clients from across the globe such as Ingersoll Rand–Trane, Dow Chemical Company, Hitachi Europe GmbH increasing its impact globally [text removed for publication]. [5.11]

5. Sources to corroborate the impact (indicative maximum of 10 references)

5.1 [text removed for publication].

5.2 Simerics announcement of the Partnership with PDM https://www.simerics.com/pdm-analysis-and-simerics/ & Simerics description of Simerics MP+ & SCORG use https://www.simerics.com/simulation-gallery/twin-screw-compressor/

5.3 Letter of Support by the President and CEO, Gamma Technologies LLC & Gamma Technologies description of the integration between SCORG & GT-SUITE https://www.gtisoft.com/partners/scorg-analysis-and-design-of-screw-machines/

5.4 Letter of Support by the Research and Development Manager, Howden Compressors, A Division of James Howden & Company Limited
5.5 Howden Compressors investment announcement https://www.howden.com/en-gb/news/howden-compressors-investment & Howden compressors news for launch of new oil free range of compressors Sep 2019. https://www.howden.com/en-gb/products/compressors/oil-free-screw-compressor-package
5.6 Royal Academy of Engineering: Research Chairs 11 Sep 2020 - https://www.raeng.org.uk/news/news-releases/2020/september/seven-top-university-engineers-funded-to-collabora & Howden Press Release https://www.howden.com/en-us/news/grant-received-from-raeng-en
5.7 Kirloskar Pneumatic Company Ltd Letter of Support - Vice President, Air Compressor Division & https://www.kirloskarpneumatic.com/our-offerings/air-compressors/screw-air-compressors/oil-injected-electric-skid-tank-mounted-screw-compressors/
5.8 Mayekawa MFG Letter of Support – Senior Director
5.9 11th International Conference on Compressors and their Systems – Post Conference Report.
5.10 Vert Rotors UK Ltd Announcement of New A150 Compressor Launch in the Compressor Centre Conference https://www.vertrotors.com/new-a150-product-launch/
5.11 [text removed for publication]