Institution: University of Southampton

Unit of Assessment: 15 General Engineering

Title of case study: 15-16 Tribology: saving costs and improving safety across industries

1. Summary of the impact

Surface wear in moving components can endanger human lives and costs the UK economy £24 billion every year. Excellent research in this area – known as Tribology - at the University of Southampton (UoS) led to the foundation of the national Centre of Advanced Tribology (nCATS), which collaborates with over 100 companies and institutions in many sectors. Examples of nCATS impact include research findings forming an integral part of a BNFL/Sellafield Ltd's design guide for the prevention of radioactive slurry leakage. It also enhanced GE Aviation's competitive advantage by supplying novel electrostatic wear debris sensors (the only system in use), which have been integrated into new fighter aircraft engines.

2. Underpinning research

Tribology is the science of interacting surfaces encompassing friction, wear and lubrication. All instrumentation, machinery and equipment with moving parts are susceptible to tribological issues which can adversely and sometimes catastrophically affect operations. Indeed, the resulting cost of wear to the UK economy is estimated at 1.4-1.6% of GDP annually, currently £24 billion (UK Tribology Network). Tribological failure can also be dangerous as shown when a wind turbine gearbox caught fire in Scotland in 2011, or even deadly: Alaska Airlines flight 261 crashed in 2000 with 88 fatalities due to excessive wear of a jackscrew thread in the flight control system.

In recognition of the national importance of tribology and the excellence of research in this field being conducted at the UoS by a group led by Professor Robert Wood, the national Centre for Advanced Tribology at Southampton (nCATS) was established in 2008 with £10 million of investment, and began recruiting its present 39 multidisciplinary researchers. Research areas of expertise include: corrosion and electrochemical sensors (Dr Julian Wharton, 1998-); condition monitoring and electrostatic sensors, or ES (Dr Ling Wang, 2001-); cartilage health for orthopaedic applications (Dr Martin Stolz, 2009-); friction on materials such as skin, wrinkle development, and tissue damage and healing (Dr Georges Limbert, 2007-); biological microfilms with applications ranging from anti-microbial coatings for surgical implants and safe dental plaque removal, to anti-fouling coatings for ships' hulls (Dr Paul Stoodley, 2010-); the chemistry of lubricants (Dr Monica Ratoi, 2009-); and coatings, notably the replacement of toxic hexavalent chromium (Dr Thomas Polcar, 2011-).

There is not enough space to expand on all of nCATS impacts, so two have been selected to highlight the Centre's standing as the national centre for tribology in the UK.

Professor Wood has led long-running tribological research (1999-2009) with British Nuclear Fuels Ltd (BNFL) / Sellafied. This research [3.1-3.3] focused on the transfer of radioactive slurry from holding ponds to a processing plant, ensuring minimal erosion and corrosion levels caused by impingement of transported solids on internal components (e.g. pipes, pumps, valves, nozzles etc). The researchers used a scaled version of an actual pumping system highlighting the mechanism and areas of critical erosion wear, and developed engineering and materials solutions to counteract the tribological effects shown. Significant expertise (5 journal papers) and commercial scale erosion testing facilities were developed, resulting in £270k of contracts placed by BNFL with the UoS between 1999 and 2009.

Fundamental research [3.4-3.6] into electrostatic sensing of wear (ES) was carried out between 1995 and 2010. It attracted several funders: US Office of Naval Research, 1995-2003 (US$1M); ATOS project (Advanced Transmission and Oil System Concepts) funded by European Framework (FP5) with Rolls Royce, 2001-2004, (€ 5,455,128) Chevron Oronite (USA), Tribotex (Japan) and GE Aviation (UK), 2005-2010. This research focused on developing electrostatic wear site and wear debris sensors that can be utilised 'on-line' in real time. The work demonstrated that electrostatic sensors can detect advanced signs of surface distress and important surface charge information relating to oil additive interactions while a piece of machinery is running.

3. References to the research (the best 3 are starred)

Erosion of sludge handling plant for BNFL/Sellafield Ltd.

3.1 *R.J.K. Wood, and T.F. Jones, "Investigations of sand-water induced erosive wear of AISI 304L stainless steel pipes by pilot-scale and laboratory-scale testing", Wear, **255**, 2003, 206-218.

3.2 R.J.K Wood, T.F. Jones, J. Ganeshalingam, and N.J Miles, "Comparison of predicted and experimental erosion estimates in slurry ducts", Wear, **256**, 2004, 937-947.

3.3 Wood R.J.K; Jones T.F.; Miles N.J.; Ganeshalingam J, Upstream swirl-induction for reduction of erosion damage from slurries in pipeline bends, Wear, **250**, Number 1, October 2001 , pp. 770-778(9)

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3.4 *T.J. Harvey, S. Morris, R.J.K. Wood and H.E.G. Powrie, Real-time monitoring of wear debris using electrostatic sensing techniques, Proceedings of the Institute of Mechanical Engineers, Part J: Journal of Engineering Tribology, **221** (1) (2007), pp. 27–40.

3.5 Craig, M., Harvey, T. J., Wood, R. J. K., Masuda, K., Kawabata, M. and Powrie, H. E. G. (2009) Advanced condition monitoring of tapered roller bearings, part1. Tribology International, **42**, (11-12), 1846-1856.

3.6 *Booth, J.E., Nelson, K.D., Harvey, T.J., Wood, R.J.K., Wang, L., Powrie, H.E.G. and Martinez, J.G. (2006) The feasibility of using electrostatic monitoring to identify diesel lubricant additives and soot contamination interactions by factorial analysis. Tribology International, **39**, (12), 1564-1575.

4. Details of the impact

The main impacts of the research carried out by Professor Wood et al include the foundation of the nCATS centre, which collaborates with commercial companies on a large scale, as well as the direct adoption of research findings by industry.

By 2008, UK companies were lobbying the government to found a strategically important national centre for Tribology. Tribology research excellence at UoS and industrial links were instrumental in the group winning a £3.5million award from the Engineering and Physical Sciences Research Council (EPSRC); with £4 million from UoS and £2 million from industry, nCATS was launched in 2009. Today nCATS collaborates with a wide range of industries and over 100 organisations, most of them industrial. It has international standing, with collaborators in the USA (Sclumberger, Chevron, DePuy), Japan (Tribotex, Diado), China (Lanzhou Institute), EU (BMW, Vestas) and the UK (RR, Shell, Airbus).

A major remit of nCATS is collaboration with industry to enhance UK companies' tribological competitiveness. The centre's ~£200k of consultancy annually delivers real solutions: it achieved a 20% increase in the stability and mechanical efficiency of worm gears in industrial actuators for Rotork (17% world market share in gears and controls). Knowledge transfer in 2009 concerning gear face patterns and lubrication regimes enabled the company to launch a new product (IQ3) within a shorter time frame. In fact the work by nCATS has been applicable to products accounting for 80% of Rotork Controls profits (£30 million). Adrian Landa from Rotork states "*Working with nCATS has helped us produce more efficient, stable and reliable gears which have led to a new product being launched (IQ3) with a better understanding of variation caused by the manufacturing processes. The knowledge transfer has helped us to think about our designs in different ways. We are also now able to question our supply chain with more confidence and knowledge in both technical and statutory (REACh etc.) requirements of lubricants and gear components ie we are now an informed customer. We continue to have fantastic commercial success and believe the work of nCATS will help us realise an increase in our £30m profits* [5.1].

John Crane UK Ltd (30% market share in seals) came to nCATS in 2012 for advice when experiencing electrostatic discharge that was damaging power generation gas seals and threatening a large commercial contract. nCATS conducted a suite of reciprocating wear tests and monitored for electrostatic discharge. The mechanism and reasons for discharge were fully explained and alternative materials suggested. John Crane has implemented these materials

changes and the multi-million pound commercial contract has been successful. Ian Goldswain states "*The work conducted by nCATS for John Crane UK Ltd contributed significantly to the successful understanding of the causes of electrostatic discharge (ESD) in a turbomachinery application which proved to be vital to a major business agreement between John Crane and a key customer in the oil & gas market*" [5.2].

Direct research impacts on industry include changes to how BNFL processes its radioactive slurry. UoS results were included in a 2003 BNFL Design Guide [5.3a] for slurry handling pipework and components (risk of leaks from erosion), and although this guide itself was published before the impact assessment period, nuclear industry lead times mean that UoS research has continued impacting designs since 2008. The guide has been adopted throughout BNFL, with no failures or shutdowns reported since publication. This work is critical: rules issued by the Health and Safety Executive demand that BNFL pumps and processes the slurry without any leakages during plant lifetime, due to the radioactive nature of the slurry. Sellafield Ltd, the company responsible for nuclear decommissioning and waste management, placed several further projects with nCATS, most recently - in 2011 - an independent technical review of an internal desktop wear study of jet erosion from sludge handling plant agitators (RI*f*l Document Refs. 08/SQ/00455/R and 00709/R) [5.3b,c]. This study highlighted the vulnerability of stainless steel valve parts to erosion. Erosion damage was avoided by Sellafied employing a more erosion resistant material in the identified parts of valves. This improved design was put forward for a BNFL award [5.3d]. Gulab Mistry states "*The two studies have enabled the equipment design and the selection of the materials of construction for a new sludge storage plant as part of a Sellafied remediation programme. The knowledge has been shared internally with other Sellafield projects*"[5.3e]

In the area of wear detection, existing engine and gearbox wear debris detection systems rely on the magnetic property of debris. Through their research activity, nCATS developed an Electrostatic Sensor (ES) which can detect ceramic (as well as ferrous) wear debris [5.4a]. The system also monitors oil quality and tribofilm health through surface charge characterisation. These sensors work in real time online, are more energy and economically efficient, and monitor both wear sites and debris. In between 2003-2006 GE Aviation integrated this technology into its commercial sensor system (the only system commercially with ES sensors), now used on the F35 Joint Strike Fighter Lightning II aircraft engine (3 ES per engine) - currently the only ES in production. GE Aviation predicts provision of sensor systems for 6000 jet engines by 2025; spares could increase this. Honor Powrie states, "*Work performed by nCATS (at Southampton University) has improved understanding of the application of electrostatic sensors for oil system health monitoring, including mechanical component condition and oil quality. This has helped better quantify capability and limitations, which is important when assessing the readiness and uniqueness of such a technology. Collecting and analysing multiple sensor data, again from oil system bench test monitoring, has demonstrated some of the relative merits of the different sensing approaches, as well as the usefulness of multiple sensor analysis for enhanced fault detection and diagnosis*" [5.4b].

As a national centre, nCATS sees dissemination of tribology expertise, especially to industry, as a major part of its remit. To this end, major events have been run such as a Marine Energy Systems day (supported by the IMechE, EPSRC, IET, IOP and IOM^3) with ~60 attendees; a Functional Coatings for Industry day supported by the Materials KTN with ~100 attendees; Tribology at Sea day supported by the IMechE with ~65 attendees; and hosting the Faraday Discussion on Tribology supported by the RSC with over 100 attendees. Breakout sessions at these events helped shape an EU ERC bid and TSB consortium. nCATS has also gone on to directly perform consultancy and research for a number of company contacts made at these events. Two Knowledge Transfer Partnership bids have also been submitted and the Materials KTN has requested nCATS to run another dissemination event.

Other outreach has included an interview by BBC Radio Solent concerning the benefits of nCATS to industry and a webinar about the economics of tribology through the UK Tribology Network (>40 logged in) of which Professor Wood is the Chair. Outreach to children has included INTECH Science Centre at Winchester where two large fixed demonstrator models allow children to appreciate friction and material choices. An educational video where complex tribology concepts have been presented in simplified terms has also been produced with outreach funds from a "Green Tribology" EPSRC Platform Grant (EP/J001023/1) [5.5].

5. Sources to corroborate the impact

Actuator Worm Gears

[5.1] Mechanical Design Manager, Rotork

Power Generation Gas Seals

[5.2] Director, Research & Development, John Crane Ltd

Erosion of sludge handling plant for BNFL/Sellafield Ltd

[5.3a] Lynn G, "Hydraulic Slurry Transfer Systems - Assessment Guide", BNFL, 2003.

[5.3b] Sludge packaging plant erosion study: RI*f*I Final report, 08/SQ/00455/R, Sept 2009.

[5.3c] Independent review of desktop erosion study of Xomox valves, RIfI Report, 00709/R, Aug, 2011)

[5.3d] Available from UoS document repostitory

[5.3e] Senior Technical Specialist, Sellafield Ltd

Further Journal Papers

J.A. Wharton and R.J.K Wood, "Influence of the flow conditions on the corrosion of AISI 304L stailess steel", Wear, **256**, 2004, 525-536.

J.A. Wharton and R.J.K Wood, "Flow corrosion behaviour of austenitic stainless steels UNSS30402 and UNSS31603", Corrosion, **61**, 2005, 792-806.

R.J.K Wood and T.F. Jones, "Investigations of sand-water indusced erosive wear of AISI 304L stainless steel pipes by pilot scale and laboratory-scales testing", Wear, **255**, 2003, 206-218.

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[5.4a] http://www.transport-research.info/web/projects/project_details.cfm?id=14376&page=funding

[5.4b] Prof Honor Powrie, GE Aviation

Outreach

[5.5] Educational video where complex tribology concepts have been presented in simplified terms (http://www.soton.ac.uk/isolutions/essentials/media/watch.php?vidid=c6c0278)