Institution: University of Sheffield

Unit of Assessment: 12A - Aeronautical, Mechanical, Chemical and Manufacturing Engineering: **Mechanical Engineering and Advanced Manufacturing**

Title of case study: Engineering companies benefit from improved sensor design for tribological machine elements.

1. Summary of the impact

This research, performed in the Department of Mechanical Engineering at Sheffield, has provided a unique method for measuring oil films in real engineering components like ball-bearings, thrust pads, seals, and piston rings. Adopted by leading industrial customers across Europe, the resulting benefits include the development of new seal designs and piston ring-pack products as well as trouble-shooting pump failure. The spin-out company, Tribosonics Ltd., which manufactures the instrumentation under licence and provides consultancy services, currently employs eight people and turned over £450k in 2012 (£600k expected in 2013). Customers include [*text removed for publication*] who have seen their new ring pack reduce oil consumption by up to 40%, saving $160K per year per engine and [*text removed for publication*] whose seals designed and tested using our methods have 10% of the leakage of conventional seals.

2. Underpinning research

The underlying research consists of methods and devices to determine oil film thickness from pulses of ultrasound reflected at lubricated contacts.

All lubricated machinery relies on a thin film of oil to keep surfaces separated and so reduce friction and wear. These films are very thin (typically ranging in thickness from 10nm to 100 μm) and have proved difficult to measure. There are several measurement techniques that have been used in the past (reflected light, electrical resistance, and capacitance). Without exception these methods require significant changes to the machine elements being measured, for example drilling holes into cylinder liners, or imbedding probes into surfaces. This is experimentally difficult to achieve, costly, and disrupts the very thin oil films. This has meant that in the past direct oil film measurement is usually limited to the laboratory. Ultrasound has the key advantage that it is non-invasive and can measure the contact through the machine parts.

The underpinning research [R1-R3] used fundamental elastic wave mechanics to show how an interface responds to an ultrasonic pulse. For most practical cases the interface can be modelled as a simple non-linear spring; and reflection depends on the stiffness of that spring. In turn the spring stiffness depends on the thickness of an oil film or the amount of solid contact. The significance of this new approach is that simple, cheap, and small piezo-electric sensors can be bonded onto the outside of the component for non-invasive measurements. This has allowed for the first time measurements on real components in full scale industrial machines.

Pathway from research to impact

(a) 1997-2002: Early work to develop the algorithms and instrumentation for measuring oil films was funded by three key EPSRC grants (GR/S46963, GR/M90191, GR/L89020). The methods were experimentally validated on laboratory based bearings and model contacts and encapsulated in three pioneering papers that describe how ultrasound responds to tribological interfaces (i.e. oil films, asperity contact, and mixed lubrication films) [R1-R3].

(b) 2002: IP Protection. The scientific concept was patented in three regional patents (GB 2370354, US7066027, EP1314001) and is jointly held by Sheffield and Bristol (60:40 royalty split).

(c) 2003-date: System Refinement. Work focused on making the techniques industrially viable, and expanding the portfolio of measurement solutions. This has involved extensive calibration and validation, development of high speed data capture, dealing with harsh environments, and manufacturing simple cheap sensors and instrumentation [R4-R6].

(d) 2005-date: Industry Trials and Technology Transfer. Most of the technology refinement was done in collaboration with industrial partners on a consultancy basis. The learning was carried out on-site with partners where technical problems were solved as they arose. Examples of these on-site trials are: [*text removed for publication*].

(e) 2012-date: On-going Development. The technology continues to be enhanced to increase scope of application. Recent developments have covered the more challenging applications of sheet metal rolling and automotive piston rings.

Summary of staff involved

The team that created this impact was led by Professor Dwyer-Joyce supported by PhD students and Research Assistants (notably Dr Harper, Dr Reddyhoff, Dr Donohoe, Dr Mills, Dr Hunter, and Dr Vail). The first stage of the work was carried out with the University of Bristol NDT group (Professor Drinkwater). They provided the basic ultrasonic tools and instruments that were implemented in the Sheffield laboratory. The second phase of the work (industrial applications) was carried out solely by the Sheffield team.

3. References to the research

References that best indicate the quality of the research are indicated with asterisks (***).

R1.***Dwyer-Joyce, R.S., Drinkwater, B.W., and Donohoe, C.J., (2002), *The Measurement of Lubricant Film Thickness using Ultrasound*, Proceedings of the Royal Society Series A, Vol. 459, pp 957-976. (doi: 10.1098/rspa.2002.1018).

R2.***Drinkwater, B. W., Dwyer-Joyce, R. S., and Cawley, P., (1996), *A Study of the Interaction between Ultrasound and a Partially Contacting Solid-Solid Interface*, Proceedings of the Royal Society Series A, Vol. 452, No. 1955, pp. 2613-2628, London. (doi: 10.1098/rspa.1996.0139).

R3.***Dwyer-Joyce, R.S., Reddyhoff, T. and Zhu, J., (2011), *Ultrasonic Measurement for Film Thickness and Solid Contact in Elastohydrodynamic Lubrication*, ASME Journal of Tribology, Vol. 133, Issue 3, 031501. (doi:10.1115/1.4004105).

R4. Reddyhoff, T., Dwyer-Joyce, R.S., and Harper, P., (2008) *A New Approach for the Measurement of Film Thickness in Liquid Face Seals*, Tribology Transactions, Vol. 51, No. 2, pp. 140 - 149. (doi: 10.1080/10402000801918080).

R5. Kasolang, S. and Dwyer-Joyce, R.S. (2008), *Observations of film thickness profile and cavitation around a journal bearing circumference*, Tribology Transactions, Vol. 51(2), pp 231-245. (doi: 10.1080/10402000801947717).

R6. Mills, R.S., Avan,E.Y., and Dwyer-Joyce, R.S., (2013), *Piezo-electric sensors to monitor lubricant film thickness at piston-cylinder contacts in a fired engine*, Proceedings of the Institution of Mechanical Engineers, Part J, Journal of Engineering Tribology, Vol. 227, No. 2, pp. 100-111. (doi: 10.1177/1350650112464833).

4. Details of the impact

Spin-Out & Commercialisation Activity

A spin-out company called Tribosonics Ltd [S1] was incorporated in 2006, with a start-up fund of £40k won competitively from the ERA Foundation and the RAEng. The company is run by Dr Phil Harper and is largely staffed by PhD graduates from the Sheffield group. The business model covers the manufacture and sales of oil film monitoring equipment and the provision of testing and installation services. Tribosonics manufactures full specification instruments named FMS50, FMS100, and FMS200 (selling price £18k-£40k) and a cut-down miniaturised version the T-200 (selling price £0.8k-£2k). The University owned IP is licenced to Tribosonics who pay a royalty on each instrument sold.

Since 2009, nine sets of full specification equipment, with a combined value of £325k, have been purchased by [text removed for publication]. These span the lubricant, seal, and bearing manufacturers, and geographically the UK, Europe and Asia markets.

Customers for whom consultancy test services have been provided include: [text removed for publication]. The company has a current (2012 figure) annual turnover of £450k/year and employs 8 staff.

Critical Impact on Industrial Practice

[text removed for publication]

5. Sources to corroborate the impact

S1. Corroborating statements available from Managing Director, Tribosonics Ltd., Sheffield. U.K.

S2. [text removed for publication].

S3. [text removed for publication].

S4. Journal Paper. Smith, O. and Sutton, M. (2011), 'Fuel economy in heavy duty diesel engines. Part 1: measurement of oil film thickness on an operating engine: Measurement of oil film thickness on an operating engine', Proc. Inst. Mech. Eng., Part J: J. Eng. Trib. doi:10.1177/1350650111400342

S5. [text removed for publication].

S6. [text removed for publication].

S7. [text removed for publication].