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| <p>Institution: Edinburgh Research Partnership in Engineering - ERPE (Heriot Watt/Edinburgh)</p> |
| <p>Unit of Assessment: B15: General Engineering</p> |
| <p>Title of case study: Hand-tool Vibration Monitor Improves Health and Safety of Construction Workers</p> |
| <p>1. Summary of the impact (indicative maximum 100 words) As 288,000 UK construction workers were estimated to have contracted vibration white finger and 170,000 had claimed compensation by 2011 this study relates to the design and development of a hand and arm vibration (HAVmeter) monitor by the ERPE Reactec student start-up company. This company initially focussed on optimisation of sweeping for curlers, contributing to team GB winning the 2002 Winter Olympic Gold medal. The current Reactec (HAVmeter) instrument measures and reports on vibration white finger, which potentially affects 5 million British workers.</p> <p>The HAVmeter has sales in excess of £9M, over the 2008-2013 period, and is now in use by 45,000 construction workers. Reactec, with 23 employees and a turnover of ~£2.5M p.a., company innovation has been recognised with 4 industrial awards since 2009.</p> |
| <p>2. Underpinning research (indicative maximum 500 words) ERPE established a research group in Snow and Ice Mechanics in Engineering in 2000 comprising Blackford (Senior Lecturer throughout period), with Marmo (PDRA to 2006), assisted by Buckingham (PhD award 2007) and Watson (PhD award 2004). This group now has a strong international reputation, with unique experimental facilities, and industrial and academic collaborations in EU, USA and Asia.</p> <p>The important ERPE research and other contributions which have underpinned the development of Reactec and Xi Engineering were:</p> <ul style="list-style-type: none"> • Development of expertise on the fundamentals of ice friction [2]. • Examining the application of this expertise to winter sports [1, 3, 4]. • Technology transfer to enable the creation of Reactec [5] and growth of new product based on the previous expertise. • Extension to improving car tyre design and to securing a new £170k cold testing facility. <p>The underpinning research from 2000 to 2004, leading to the formation of Reactec focused on (a) skis that sense and react to their environment, and (b) on the mechanics of snowboards with the aim of linking their movement to participant performance [3]. Instrumented curling brushes were designed and built to characterize a players performance dynamics during sweeping [1, 4]. The most advanced version of the “sweep ergometer” (instrumented brush) was prototyped by Reactec in 2005. The output was combined with a thermo-mechanical model that was based on the heat generated by sweeping and how that influences ice friction, which enabled optimisation of sweeping for Team-GB Olympic curlers [4] and contributed to their winning the 2002 Winter Olympic Gold medal.</p> <p>The initial aim of the research was to analyse the mechanics of skis using embedded sensors. This research led to insights into the potential of smart/responsive materials and resulted in the concept of “smart skis” where the dynamic behaviour of the ski is quantified using piezoelectric sensors, and a magneto-rheological fluid based actuator alters the skis’ mechanical properties to optimize performance [5].</p> <p>The foundations for the research methodology can be traced back to the basic engineering research on sensors in vibrating systems, which provided the capability to monitor the dynamics of the systems. This was supported by two PhD case awards and £10k of Edinburgh Technology Fund investment [5]. This work provided evidence of proof of concept techniques and expertise for subsequent vibration characterization in more complicated situations.</p> <p>The company, formed in 2000 by PhD students Watson and Buckingham, initially focused on</p> |

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developing an active ski, which would measure, monitor and react to the changing conditions of the slope. This research was predominantly focused on skis and snowboards, leading to the development of proof of concept systems, which were demonstrated to the major market players. The measurement systems that had been used during this ski based proof-of-concept phase were later adapted to develop improved monitoring equipment for curling brushes. The initial patents were filed in 2001 and subsequently awarded as GB 200510277.

The smart controller from the ski platform was subsequently adapted for use in the construction industry when Reactec commenced the design of a solution for worker health protection, with the resulting HAVmeter now being the market leader for the monitoring of these vibrations.

Current research on snow and ice is focussing on improving car tyre design, in association with a major European tyre manufacturer, and they have funded the installation of a new £170k cold testing facility.

3. References to the research

References identified with * are those which best indicate the quality of the underpinning research

[1]* Buckingham, M.P., Marmo, B.A. and Blackford, J.R., "Design and use of an instrumented curling brush", Proceedings Institution of Mechanical Engineers, Part L: J. Materials Design and Applications, Vol. 220, Issue L4, pp. 199-205, 2006. DOI:[10.1243/14644207JMDA70](https://doi.org/10.1243/14644207JMDA70). *Invited paper* describing the instrumented curling brush development and how it was used with the Olympic team to aid their training.

[2]* Marmo, B.A., Blackford, J.R. and Jeffree, C.E., "Wear surfaces and friction maps from kinetic friction on ice surfaces", Journal of Glaciology, Vol. 51, No.174, pp. 391-398, 2005. DOI:[10.3189/172756505781829304](https://doi.org/10.3189/172756505781829304). 17 GS citations

This provides fundamental insights into ice friction: the innovative experimental methodology developed enabled ice sliding mechanisms to be observed for the first time at sub-micron resolution.

[3]* Buckingham, M.P. and Blackford, J.R., "Analysing snowboard mechanics", in 5th International Conference on Snow Engineering, Davos, Switzerland, July 2004, Publisher Balkema. Available on request.

An invited paper at an international conference, it presents characterisation of snowboard mechanics, from embedded sensors, and uses the data to quantify differences in performance and aid athlete technique training.

[4] Marmo, B.A., Buckingham, M.P. and Blackford, J.R., "Optimising Sweeping Techniques for Olympic Curlers", in 6th International Sports Engineering Conference, Munich, Germany, June 2006. Available on request.

Awarded top conference prize for best contribution to Olympic and Paralympic Sports. This presents a model, using the output of the instrumented brush [1], which is used for developing sweeping strategies for the gold medal winning GB curling team.

[5] Buckingham, M.P., Watson, P. and Blackford, J.R., "Reactec – from laboratory to the slopes – commercialisation of university research", in 5th International Sports Engineering Conference, Davis, California, September 2004. Available on Request.

This describes how Reactec evolved from within the University.

4. Details of the impact (indicative maximum 750 words)

Responding to the needs of the Health and Safety Executive (HSE) who estimated, during the 1990s, that around five million British workers were exposed to hand-arm vibration in the workplace. Approximately 1.7 million were believed to be exposed at levels above the exposure action value with around 900,000 of these exposed above the current exposure limit value (<http://www.hse.gov.uk/foi/internalops/fod/inspect/hav.pdf>). About 288,000 people were estimated to have contracted vibration white finger while the number of claimants, in June 2011, was 170,000

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workers: <https://www.gov.uk/government/publications/vibration-white-finger-compensation-scheme-statistics>. According to the 5th European Working Conditions Survey (www.eurofound.europa.eu/pubdocs/2011/82/en/1/EF1182EN.pdf) reported levels of exposure to physical risks in the workplace have not diminished much since 1991 and 23% of the workforce are exposed to health damaging vibrations for a quarter of their working time or more, which is similar to levels observed in 1995.

Prompted by the HSE's release of the Control of Vibrations at Work Regulations 2005, Reactec commenced in 2001 the development of a solution with Marmo, which would provide total health protection for the worker as well as real cost benefits for the employer: the HAVmeter. Here the ski controller platform [5], and the expertise from the instrumented curling brush [1, 4], were combined and extended into a measurement device for preventing hand arm vibration (HAV) syndrome amongst operators of power tools such as construction workers.

The HAVmeter measures vibration using one of two 3-axis, MEMS accelerometers, with an acceleration range between 2g and 10g. This permits the system to work across the range of hand held power tools including small drills through to large jackhammers. The unit applies a custom filter to ensure that it is detecting an active tool before selecting the best signal to noise ratio within three accelerometer ranges. Once the optimal sensor range has been chosen, the HAVmeter then applies a Fast Fourier Transform and adjusts for hand transmitted vibration from BS 5349-1 to indicate the vibration dosage.

The commercial and occupational safety benefits arising from this new product design are:

- Design and developments of the HAVmeter for monitoring hand arm vibration from hand tools by the spin-out company Reactec. This novel product was quickly established as the industry standard vibration monitoring device.
- The HAVmeter has led to improvements in health and safety for the construction and related industry sectors, where around five million British workers are exposed to hand-arm vibration.
- Sale of these devices between 2008 and 2013 have exceeded £9M, which corresponds to an estimated 15,000 HAVmeters with an estimated 45,000 users.
- A further spin-out company was formed from Reactec, Xi Engineering Consultants, which now provides dynamic modelling and analysis for a range of vibration-related issues.

Reactec Ltd was initiated from an Edinburgh Technology Fund business plan competition. Reactec went on to diversify and create the robust HAVmeter. *"I couldn't believe the HAVmeter could survive those conditions. When we saw it slip into a flooded cavity, we thought we'd never see it again. However, when we found it again two months later, we just took it out, wiped it down, and carried on using it. It is a very impressive and resilient piece of technology."* Site Foreman, Interlink M74 Project [S1].

The initial support and funding allowed Reactec to grow and raise £2.8M in investment, involving Archangel investment over 2005-11 totalling £2.3M with Scottish Government co-investment funding of £0.5M. Reactec now employs 23 people and generates profits on a turnover of ~£2.5M p.a. In 2012 Reactec secured a place in the Deloitte FAST 50 UK Awards for the second consecutive year and was one of only 5 Scottish companies to be included in the list.

Key to the HAVmeter's success has been the automated approach to report generation and the accuracy and detail obtained from using the product to monitor and protect workers' HAV exposure. *"Before the HAVmeter, we relied on manual input, with a guy basically using his memory at the end of the day for the time that he has spent using vibratory tools. With the HAVmeter, we have an accurate, user friendly piece of kit which allows us to manage HAV more easily. It really is a Health and Safety Management tool. We have been able to make major savings through cutting out administrative costs."* Roads Manager, AMEY North Lanarkshire [S2].

HAVmeter monitoring has now been adopted as standard policy in companies such as Balfour Beatty, Tarmac, Morrison Construction, Environment Agency, Aston Martin, Amey, Carillion and many more organisations which use hand held power tools. The HAVmeter product enables companies to more effectively and accurately monitor and control the exposure of their workers to vibration hazards. *“Paper based systems never really worked, the HAVmeter replaced that system with the latest technology which allows us to accurately measure and monitor our employees’ exposure to HAVs...After rolling it out we are seeing a positive result from the workforce who like the system and think it is easy to use. It’s great for self-monitoring and the tool tags can also be used as a tracking device... It’s very difficult to quantify what sort of amount of exposure an individual has had - the HAVmeter provides the perfect solution”*. National Contracting Director, Tarmac [S3].

Additional HAVmeter user quotes can be viewed at: <http://www.reactec.com/reactec/clients/case-studies> [S5].

Key industry recognitions for Reactec are: 2011 European Rental Safety Award (by Hire Industry, <http://www.hae.org.uk>), 2010 National Joint Utilities Group (NJUG) Vision on Safety for Hand Arm Vibration (<http://www.njug.org.uk>), 2009 Wimpey Minerals Trophy for Occupational Good Health (<http://reactec.com/reactec/about-us/awards>).

In order to broaden the company's reach, in 2011 the Reactec Board formed Xi Engineering Consultants to provide dynamic modelling and analysis across an increased portfolio of markets solving a wide range of vibration issues. *“As former CEO of Reactec and now Managing Director of Xi Engineering I can verify that the early research to develop the sensor and data capture systems and expertise to analyse the output was instrumental in laying the foundations to create the underpinning technology that ultimately became the HAVmeter. This created a solid foundation that Reactec is based on, and from which we were able to establish Xi Engineering”* Managing Director, Xi Engineering [S4].

In addition to the industrial transfer of Buckingham, Watson and Marmo, Iain Roberts (PhD in Blackford’s group) subsequently joined Xi Engineering Consultants in 2011.

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

[S1] Site Foreman, Interlink M74 Project, see comments included in Section 4.

[S2] Roads Manager, AMEY North Lanarkshire, see comments included in Section 4.

[S3] National Contracting Director, Tarmac, see comments included in Section 4.

[S4] Ex Reactec CEO, now Managing Director of Xi Engineering, see comments included in Section 4.

[S5] Further HAVmeter user quotes are available at: <http://www.reactec.com/reactec/clients/case-studies>.