Institution: Loughborough University

Unit of Assessment: B12 Aeronautical, Mechanical, Chemical and Manufacturing Engineering

Title of case study: Vibro-impact systems that protect hand-tool operators' health

1. Summary of the impact (indicative maximum 100 words)

Since 1995, Loughborough's research into vibro-impact systems (VIS) has made handheld breaker tools safer for operators and has also increased machining efficiency. Users have been prone to detrimental 'hand arm vibration' effects of multiple impacts, including the debilitating condition 'white finger'. JCB applied the research findings in its HM25LV breaker design, introduced in 2008, which despite being more powerful exhibits half the hand arm vibration of competitors. JCB has sold more than 1,800 units in the UK and abroad.

2. Underpinning research (indicative maximum 500 words)

Percussion machines are efficient and effective work tools; multiple impacts enable considerable work by tools with low-powered sources of excitation. However, such repetitive impacts are strongly non-linear dynamic processes and can have severe and damaging effects on operators. At Loughborough University (LU) Professor Vladimir Babitsky (1995–2011 and 2013-present) has been developing the foundations of the mechanics of vibro-impact systems since 1995, using ideas of non-linear dynamics. Through this research, Professor Babitsky formulated and solved a general dynamic problem for the optimal dynamic cycle of hand-held percussion machines **[3.1-3.3]**. Notwithstanding strict requirements for operational parameters of hand-held machines, hundreds of thousands of their operators are injured, with diseases ranging from so called 'white finger' to paralysis.

The rigorous mathematical solution of the problem of optimal dynamic cycle of hand-held percussion machines was based on Prof. Babitsky's methods of structural synthesis of the strongly nonlinear VIS. Computer simulations and experimental studies proved the effectiveness of theoretical predictions **[3.1, 3.4-3.6]** and led to the discovery of the existence of the dynamic cycle of excitation of the hand-held percussion machines with vibration-free handles **[3.1]**, which enabled the development of the new type of heavy hydraulic breaker with low emission of hazardous vibration. The breaker's general dynamic model was developed as a multi-body VIS, for which a stable and robust solution was found and validated **[3.1, 3.6]**. The engineering synthesis of the suggested optimal structure requested development of a special mechanism with zero differential stiffness. A hydro-pneumatic unit with zero stiffness was developed and tested successfully on a modified commercially available heavy-duty hand-held hydraulic breaker produced by JCB. More than a twofold increase in vibration suppression in the developed experimental model was registered compared to the original breaker with spring-suspended handles. The research and development were conducted at LU's Wolfson School Vibration Laboratory, mostly by Dr Ilya Sokolov (1999-2007) under the supervision of Profs Babitsky and Neil Halliwell (1990-2011), as well as RAs and PhDs of Prof. Babitsky's group, see list at end of section.

LU personnel engaged in this research: V Babitsky (Professor 1995–2011 and 2013-present); N Halliwell (Professor 1990-2011), I Sokolov (Research Associate 1997-2005), A Veprik (Senior Lecturer 1995-2005), E Golysheva (Research Student 2000 – 2004)

3. References to the research (indicative maximum of six references)

3.1. V. Babitsky, Theory of Vibro-Impact Systems and Applications, Springer, Berlin, Heidelberg, New York, 1998, 1-319, ISBN 3-540-63723-0. This output can be made available at request from Loughborough University.

3.2. V. Babitsky, Hand-held percussion machine as discrete nonlinear converter, J Sound Vibrat., 1998, Vol. 214, 165-182. DOI: 10.1006/jsvi.1998.1559.

3.3. V.K. Astashev, V. Babitsky, M.Z. Kolovsky, Dynamics and Control of Machines, Springer, Berlin, Heidelberg, New York, 2000, 1-233, ISBN3-540-63722-2. This output can be made available at request from Loughborough University.
3.4. E.V. Golysheva, V. Babitsky, A. Veprik, 'Dynamic correction of the excitation in hand-held electro-pneumatic percussion machines", J Sound Vibrat., 2003, Vol. 259, 829-843. DOI: 10.1006/jsvi.2002.5124.
3.5. E. Golysheva, V. Babitsky, A. Veprik, Vibration protection for an operator of a hand held percussion machine, J. Sound Vibrat., 2004, Vol. 274, 351-367. DOI:10.1016/j.jsv.2003.05.019
3.6. I.J. Sokolov, V. Babitsky, N.A. Halliwell, Hand-held percussion machines with low emission of hazardous vibration, J. Sound Vibrat., 2007, Vol. 306, 59-73. DOI:10.1016/j.jsv.2007.05.044

Key research grants:
2003-2004 EPSRC ROPA: Self-Oscillatory System of Percussive - Rotary Drilling, V.I. Babitsky, £60,880
1997-2000 EPSRC Autoresonant Ultrasonic System for Machining of Hard and Brittle Materials, V.I. Babitsky, £52,927
1999-2002 EPSRC JREI: Vibro-Impact Processing of Materials, V.I. Babitsky (PI) & N. Halliwell, £50,478
2004-2007 EPSRC An International Interdisciplinary Network on Vibro-Impact Systems (ININOVIS), V.I. Babitsky (PI) & V. Silberschmidt, £61,941

This research lead to multiple publications, including invited papers in *Journal of Sound and Vibration* (impact factor 1.613) and others (more than 15 peer-reviewed papers in total and a monograph published by Springer). Researchers were also invited to make keynote, plenary or invited lectures at the leading international events in this area, including 1st, 2nd and 3rd International Conference on Vibro-Impact Systems (2006, Loughborough, UK; 2010, Sanya, China and 2013, Leinsweiler, Germany, respectively).

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

In this section we present evidence that our research, as cited in s2 and s3, has led to the following major impact: a commercial product to prevent Hand Arm Vibration Syndrome (HAVS), working with JCB, a leading manufacturer of hand tools in the UK and which has both economic and health benefits.

A profound understanding of the mechanics of VIS, as shown in our research in s2 and 3 **[3.1-3.6]**, led Prof. Babitsky's group to their important breakthrough, enabling a significant reduction of vibration in the handles of heavy breakers – a tool used all over the world. It was the main focus of collaboration with the global tool manufacturer JCB that culminated in a mutual project on a breaker in 2001, with LU developing both the theoretical backgrounds and principal design ideas that were implemented in a specific design at JCB.

As a result, in 2008 JCB launched its new, safer yet more powerful commercial breaker HMLV25, which it continues to sell in its markets around the world. More than 1,800 units had been sold by 2013 with export markets including Australia, Azerbaijan, North America, Oman and Russia **[5.1]**. Operators can use it for longer without incurring the risks of irreversible and significant harm to their health. The design solution was patented worldwide by JCB in 2008 under the names of its inventors from Loughborough University, viz. Prof Babitsky and Dr Sokolov and JCB, Mr Malkin **[5.2]**.

In 2008 JCB stated that "the unique system dispenses with the traditional design" and that "vibration levels on competing machines start at more than double" the level for HM25LV. As a result, "operators can now safely use the machine for a full eight-hour working day without risk of exceeding recommended Hand Arm Vibration levels". It added that "the HM25LV marks the start of a new generation of handheld breaker design." **[5.3]**

When purchasing the product in 2009, one of the end-users, Tarmac National Contracting, stated: "Within Tarmac, the health of our staff is of paramount importance particularly with regard to HAVS… the vibration level of the breakers was the main driver in our decision-making process. Tests were carried out on the HM25LV, confirming JCB's claims that they are the lowest available." **[5.4]**

For an understanding of the scale of the problem addressed by the JCB breaker and its underpinning research, the Health and Safety Executive estimates two million people in the UK alone are at risk of HAVS. The estimated annual cost of HAVS to the British economy is about £447M **[5.5]**. There is no effective treatment available for the vascular symptoms and neurological component of HAVS. The best way to deal with HAVS is to prevent it, by reducing the levels of vibration operators are exposed to.

Before the 2000s global research into the mechanics of vibro-impact systems, elucidating beneficial and detrimental effects of multiple impacting, was undertaken by separate research groups in a few countries. Loughborough University decided to increase awareness of, and foster collaboration between, researchers in this field and end-users. In 2004 it established the International Centre of Vibro-Impact Systems (ICoVIS), supported by the EPSRC. The Centre unites more than 25 main research groups from more than 20 countries working in this area. Its international events serve to disseminate research to academic and industrial audiences. To date, these events have been held in the UK, USA, Japan, China, Italy, Morocco and Germany (see e.g. **[5.6, 5.7]**). A series of special issues of major journals have been published, as have several books. ICoVIS has become a first contact point for industry on various aspects of VIS; among its members are also industrial companies, in particular, JCB. These activities allowed the establishment of the new scientific sub-area – mechanics of vibro-impact systems. This increased awareness of academic and industrial researchers about new ideas, methods and tools that can be used for design of new structures and processes increasing productivity, improving an environmental footprint and preventing catastrophic engineering failures.

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

To corroborate the impact the following sources can be made available to the panel at request:

5.1. Letter from the General Manager, JCB Attachments, Uttoxeter
5.2. Patent: A.A. Malkin, I. Sokolov, V. Babitsky, Percussion Power Tool Apparatus, (27), July 2008, United States Patent No. 7404452
5.3. JCB Attachments Director and General Manager: http://www.jcb.com/presscentre/NewsItem.aspx?ID=631
5.4. Tarmac National Plant Manager: http://www.jcb.com/presscentre/NewsItem.aspx?ID=758
5.5. Health and Safety Executive, August 20-last update, Regulatory impact assessment of the physical agents (vibration) directive 2002/44/EC. [Online], 2002. Available: http://www.hse.gov.uk/vibration/ria05.pdf
5.6. http://www.itm.kit.edu/icovis/index.php - corroboration of increased awareness about establishment of the new scientific sub-area – mechanics of vibro-impact systems
5.7. http://www.neu.edu.cn/icovis2010/ - corroboration of international activities in the area of vibro-impact systems, especially in China