Institution: City University London

Unit of Assessment: 15 General Engineering

Title of case study: Next Generation Ejection Technology for the Bulk Food Sorting Industry

1. Summary of the impact

Driven by concerns over public health and intensifying legislative demands of the food industry in Europe and USA, the reliable and effective removal of unwanted objects from food products at a processing stage is increasingly important. The assurance of food quality and safety throughout the pre- and post-harvest food chain makes this issue even more significant. The effective implementation of relevant technological solutions for food safety and quality can dictate the survival, growth and competitive edge of some major sectors of the economy.

Food sorting machines are essential for eliminating unwanted food items from the production process to ensure that quality is maintained at the highest level for consumers. Key research at City University London has led to the development of a unique solenoid actuator valve (ejector), which opens and closes a high-pressure air jet in such machines to remove defective food items more accurately and efficiently from the production line.

The sorting machines which use it have a fivefold improvement in consumer food quality and safety and are 20% more energy efficient. Sales of these machines have been enhanced by 50% as a consequence of these improvements. The new valve delivers approximately 50% less food waste during the first sorting pass and offers a fourfold reduction in power consumption, contributing positively to global agricultural sustainability. The work undertaken has also assisted the industrial partner in opening up a new market for sorting machines for sorting plastics.

2. Underpinning research

Electromagnetic (EM) actuator valves based on the solenoids of the type addressed through City's research typically need to operate in tight spaces with up to 128 individual valves squeezed into an array only a few tens of centimetres wide. Switching at between 150 and 300 cycles each second the valves can often overheat, reducing their lifespan.

To be commercially viable within the current market, a valve must have a life of more than two billion cycles between maintenance sessions. Selection of design parameters which can deliver this performance whilst complying with stringent food industry standards is critical.

City's contribution to building the next generation of valves to meet this challenge came from work done by the Computer Aided Modelling and Design Group (CAMAD) in our Sensors & Instrumentation Centre. Established by the late Professor Ludwik Finkelstein three decades ago, the Group has long-standing expertise in the use of advanced mathematical modelling and Computer Aided Design (CAD) techniques for understanding and designing sensors, actuators and other related devices.

The researchers who undertook the work contributing to this case study were Professor Sanowar Khan (a member of academic staff since 1989, Principal Investigator for both projects); Professor Kenneth Grattan (a member of academic staff since 1983, Co-investigator); Dr Mihai Rotaru (Research Assistant at City, May-October 2000); Dr Ming Cai (Research Assistant at City, 2003-2006); and Dr Kamalnathan Kajan (a City research student who performed some of the theoretical and experimental studies of the ejector valve as part of his PhD research, 2003-2006).

It is well established that the principal limitation to the lifespan of any EM actuator valve, based on the solenoid principle, is mechanical failure caused by physical wear. This process has been carefully studied and modelled by our CAMAD Group, whose work has led to the development of a new advanced precision EM-valve-based ejector system for bulk food sorting technology. This has been achieved by performance modelling and design optimisation of the ejector valve in terms of its material, geometric and operational parameters. For this relevant electric circuit, magnetic field, mechanical and thermal equations have been solved following finite element field modelling.

Further design refinement and validation of computer models have been achieved by extensive electromagnetic, thermal and mechanical tests carried out at Buhler Sortex Ltd (the industrial partner, a leading global supplier of optical sorters) on two batches of prototypes. This iterative cycle of simulation-tests-simulation has been key to achieving the tight design and performance parameters of the novel EM valve in terms of fast switching speed (150-300 Hz), large force (10 N) and extremely long lifetime – typically lasting for 3-4 billion cycles before maintenance. This has also ensured very fast opening and closing times of the valve. Specifically this has been achieved by optimising electrical (coil inductance and resistance) and magnetic circuit parameters (material, its annealing regimes, etc.) and by redesigning the valve drive circuitry.

As result of this work a novel EM valve has been developed which is unique in terms of these performance parameters. The research aims, which were achieved, were to design and develop a novel ejector valve that would use a single pulse of air to 'surgically' remove a defective food item as small as an individual grain of rice or a coffee bean, lentil or peanut, from a fast-moving stream of such foodstuffs, passing the detector at 4 m/s.

At present no other solenoid valve can match this unique combination of life, force and speed. The technology ensures a much longer lifetime of such sorting machinery, more efficient use of materials and energy and improved food quality and safety.

The initial research was funded by Buhler Sortex Ltd (May-October, 2000, £20,000). This resulted in the development of the valve. Under a further research programme funded through a DEFRA Advanced and Hygienic Food Manufacturing (AFM) Link project (September 2003 – August 2006, £241,000), research at City has now identified the inherent lifetime limitations of solenoid-based EM valves, due again to mechanical wear. With industrial partners including Buhler Sortex Ltd and Vogan & Company (now S&B Herba Foods), we have been exploring ways of extending the lifespans of our next generation of valves, using magnetic shape memory smart alloys or MSMs.

Theoretically such materials cannot be overstrained and through this approach we now have the opportunity to create a new generation of ultra-high performance valves with the potential of an infinite lifespan.

3. References to the research

Certain restrictions existed during and post-research period for wider dissemination of results due to commercial sensitivity. The main outputs were:

1. Khan S.H. (2003). Next Generation Ejection Technology, *Food Link News*, 45, Dec 2003, 12.
2. Khan S.H., Grattan K.T.V., Cai M. & Honeywood M.J. (2004). Next Generation Ejection Technology for Bulk Food Sorting, *New Food*, 3, 77-82.
3. Khan S.H., Cai M., Grattan K.T.V., Kajan K., Honeywood M. & Mills S. (2005). Design and Investigation of High-Speed, Large-Force and Long-Lifetime Electromagnetic Actuators by Finite Element Modelling, *Journal of Physics: Conference Series*, 15(5), 300-305 10.1088/1742-6596/15/1/050
4. Khan S.H., Cai M., Grattan K.T.V., Kajan K., Honeywood M. & Mills S. (2007). Computation of 3-D Magnetic Field Distribution in Long-Lifetime Electromagnetic Actuators, *IEEE Transactions on Magnetics*, 43(4), 1161-1164 10.1109/TMAG.2007.892277
5. Khan S.H. & Grattan K.T.V. (2007). High-performance pneumatic valve for optical food sorting machines, *Food Science and Technology*, 2007
6. Kajan K. (2009). Finite Element Modelling and Investigation of High Speed, Large Force and Long Lifetime Electromagnetic Actuators, PhD thesis, City University London.

The Journal of Physics and IEEE Transactions are peer-reviewed journals which are highly regarded in their field. The new research approach was described in feedback from DEFRA as excellent and noted as 'the best project ever (undertaken) in the Advanced and Hygienic Food Manufacturing portfolio'. (DEFRA email 31/12/2006).

4. Details of the impact

Driven by concerns over public health and intensifying legislative demands of the food industry in both Europe and USA, the reliable and effective removal of unwanted objects from food products at a processing stage is of increasing importance.

The assurance of food quality and safety throughout the pre- and post-harvest food chain makes this issue even more significant. The effective implementation of relevant technological solutions for food safety and quality can dictate the survival, growth and competitive edge of some major sectors of the economy.

The UK has a major role to play in this food sorting industry, as it is home to one of the world leaders in research, development and manufacture of optical bulk food sorting technologies. Buhler Sortex Ltd holds 10%-20% of the market share for sorting wet and dry products such as rice (the staple grain for half the world's population), coffee beans, peanuts, vegetables, etc. Precise market share varies over time as players enter and leave the market.

The ejector sub-system developed with Buhler Sortex Ltd as a result of the City research constitutes the prime technology for Buhler Sortex's business. The impact can be defined in a number of ways:

Economic Impacts

(a) Through our principal industrial partner: Buhler Sortex Ltd introduced the ejector sub-system developed through our research in their new generation of dry sorting machines. Their Z-series and ZHVC-series machines have been replacing the previous market leader series 90000 machines since 2000 and have enabled Buhler Sortex Ltd to maintain their current lead in the highly competitive and lucrative world food sorting industry, currently worth over £200M annually. Maintaining this lead in the UK for the next generation sorting machines adds real value to UK manufacturing. Our multi-billion cycle lifetime ejector valves fitted in the new generation of sorting machines enable Buhler Sortex Ltd to offer a machine lifetime guarantee and continuous 24/7 operation with no downtime. This is a unique selling feature that is enhancing sales by 50%. Previously Buhler Sortex Ltd had a 20% share in the global marketplace for food sorting machines. With our new ejector technology implemented in their new generation of sorting machines, Buhler Sortex Ltd is expected to increase its share by 5%-10%, a very sizeable increase considering the scale of this highly competitive market. The work also contributed to Buhler Sortex Ltd receiving three prestigious Queen's Awards (The Queen's Award for Enterprise – Innovation, 2001 and The Queen's Award for Enterprise – International Trade, 2005 and 2011).

(b) Through the UK grain milling industry: The new sorting machines are used by grain milling corporations such as Vogan & Company (now S&B Herba Foods, a major UK grain milling group). The machines provide reduced running costs for end-user food sorting industries through more efficient (less waste and energy) and reliable (no downtime) bulk food sorting. Currently, the replacement of worn out ejectors comprises a significant proportion of the cost of ownership of a sorting machine, typically around £10,000 per machine per year. The increased sorting resolution in the new machines delivers an improvement in sorting performance. With the use of new ejector valves the amount of good food product rejected after sorting has been reduced from 2% to 0.5%. In addition, the amount of good food contained in reject products after sorting has been reduced from 25% to 10%.

(c) Supplying UK industry with ejector valves: Buhler Sortex Ltd typically requires between 100,000 and 300,000 ejector valves each year for newly-built machines and as spares for machines in the field. Buhler Sortex Ltd undertakes to support machines for a ten-year life span and hence it alone generates a significant business for the ejector industry. For example the new ejector valves have generated additional business worth £3M per annum to IMI Webber, a manufacturer of solenoid valves used for controlling compressed air, inert gases, water and other fluids.

(d) Ensuring a UK technological lead and growing exports: Currently Buhler Sortex Ltd sells between 1,000 and 2,000 sorting machines per year in over 100 countries. Each machine has

an average price of £50,000 and £100,000. The period of strong growth currently being experienced by the optical food sorting industry generates worldwide sales of over £200M.

Societal Impacts

Societal impact through UK end-user consumers: A fivefold improvement in food product quality and safety has been achieved through the use of advanced sorting machines by the UK milling industry, including companies such as S&B Herba Foods. The new generation of sorting machines incorporating the new ejector valves are more effective in rejecting food products such as those affected by toxins formed during storage in wet seasons and harmful to human consumption (e.g., rice grains). The quality and safety of the food we consume is very much linked to overall public health and is therefore of major concern and interest in society. Food safety and its quality are of primary concern to the World Health Organization and the United Nation's Food and Agriculture Organisation. The acceptable level of affected product in food for human consumption is minute and strictly monitored. The new generation of sorting machines can remove imperfect grains, avoiding what could be a major food safety problem.

Environmental Impacts

The increased lifetime of the newly-developed ejector sub-systems and their increased sorting resolution and performance mean that the new sorting machines offer a fourfold reduction in power consumption. They have also reduced food wastage by up to 50% as a result of reductions in downtime and re-sorting and in servicing costs. This contributes significantly to agricultural sustainability.

Beyond the food sorting industry optical sorting is increasingly playing a major role in waste identification and separation. Through our principal industry partner Buhler Sortex Ltd improvements are also being achieved in the waste plastic industry. The new EM ejector system has the potential to boost the efficiency of this industry as it has done for the food sector, impacting positively and substantially on the efficiency of plastic recycling around the world. This has enabled Buhler Sortex Ltd to open up a new market for their machines for sorting plastics such as rPET, uPVC and HDPE.

5. Sources to corroborate the impact

- Support letter from Buhler Sortex Ltd
- Support letter from S&B Herba Foods