Institution: BRUNEL UNIVERSITY (H0113)

Unit of Assessment: 12 – Aeronautical, Mechanical, Chemical and Manufacturing Engineering

Title of case study: Regenerative Engine Braking Device for Buses and Other Commercial Vehicles

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

Prof Zhao's development of an innovative hybrid engine RegenEBD was exploited by its industrial partner, Guangxi Yuchai Machinery Company (Yuchai), the largest bus engine manufacturer in China holding 80% of the domestic market. The first RegenEBD engine buses were operated in Yulin city, where Yuchai is based, in 2011. Yuchai confirmed that these buses have demonstrated notable fuel savings of 4.7-10% (1,100-2,200 litres of fuel saving), equivalent to 3.6-7.2 tonnes of carbon saving per vehicle per year. This led Yuchai to re-align their manufacturing strategies and development efforts for 3 years (2011-2013), investing significant resources to begin manufacturing and retrofitting of RegenEBD engines in 2014. They have employed over 30 new engineers to develop and manufacture RegenEBD and purchased equipment for RegenEBD engine testing and operations. Yuchai expects that hundreds of buses equipped with RegenEBD will be on the road by 2020.

2. Underpinning research (indicative maximum 500 words)

Hybrid vehicles are known to be economical in terms of their fuel consumption particularly in urban areas where the traffic conditions involve numerous stops and starts. In such conditions, a large amount of fuel is needed to accelerate the vehicle, and much of this is converted to heat in brake friction during deceleration. The air hybrid engine recovers the braking energy and stores it for later use to start the engine and help the vehicle to accelerate, allowing significant improvement in fuel economy but without adding the large weight and complexity of an electric hybrid.

Based on the experimental research on air hybrid engines during 2004-2007, partially supported by Lotus Engineering Ltd, Prof Zhao confirmed that 2-stroke compressor mode (CM) and expander mode (EM) operations could achieve most effective air hybrid operations with Lotus's fully variable valve actuation (FVVA) system. However, the FVVA system was usually too bulky, expensive and complicated to be implemented in production engines.

In response to this, Prof Zhao and Dr Ma at Brunel University along with their industrial partners, Ford Motor Company and Lotus Engineering Ltd collaborated to develop simplified technologies for air hybrid operation in an EPSRC project, 'Innovative Air Hybrid Engine Concepts for Next Generation Fuel Efficient Road Vehicles' from 2007 to 2010. This technology utilises a new proprietary intake system design and cam profile switching (CPS) devices and allows the engine to switch between the air hybrid operation and normal engine operation [4].

In 2011, Prof Zhao's research successfully demonstrated that engine braking devices on commercial vehicles could be adapted for the air hybrid engine by relocating the devices from the exhaust valve to the intake valve. Compared to CPS devices, the production of the engine braking device is simpler and can be retro-fitted to the engine. This has led to a significantly simplified mild air hybrid engine concept, Regenerative Engine Braking Device (RegenEBD). Subsequently, Prof Zhao further developed RegenEBD in a second EPSRC sponsored project (2011-2014). The project is led by Prof Zhao and Yuchai, the largest diesel engine manufacturer in China, provides technical support including the supply of an engine and control system for the project, while Prof. R. Stobart at Loughborough University assists with technical information for control and drive cycle simulations. Prof Zhao developed the design concepts while the engineers at Yuchai implemented the concept through engineering, design, testing and optimisation so that the system and components can be produced for real engine applications with strong reliability and durability.

The research has successfully demonstrated that RegenEBD technology is capable of regenerative stop-start operations, supplying service air, or providing instant boost depending on the vehicle type and usages. A major advantage of RegenEBD is its flexible applicability: it can be retrofitted to the existing engine and transmission system without affecting the engine's normal

operation or it can be fitted as an original equipment manufacturer (OEM) option for the new vehicle. Furthermore, the most recently formulated air connector design is expected to enable a common component to be used to realise the RegenEBD technology for different engines and vehicles. In 2011, Yuchai fitted the RegenEBD engine to working city buses in Yulin city where Yuchai is based.

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

1. Zhao H, Psanis C, Ma T, Turner J, Pearson R. "Theoretical and experimental studies of air-hybrid engine operation with fully variable valve actuation." INTERNATIONAL JOURNAL OF ENGINE RESEARCH Vol.12, Part 6, pp.527-548, 2011. DOI: http://dx.doi.org/10.1177/1468087411422846
2. Zhao H., Psanis, C., Ma T., "Analysis of an Air Hybrid Engine Concept with energy recovery valve (ERV)", International Journal of Vehicles Design, Vol. 55, No. 1, pp.49–75, 2011. DOI: http://dx.doi.org/10.1504/IJVD.2011.038072
3. Zhao H., Psanis C., Ma T., "Analysis of a production-oriented air hybrid engine concept and its performance", International Journal of Powertrains Vol.1, issue.1, pp.43-77, 2011. DOI:http://dx.doi.org/10.1504/IJPT.2011.041909.
4. Lee C., Zhao H., Ma T., "Analysis of a cost effective air hybrid concept", SAE Paper 2009-01-1111, 2009. DOI: http://dx.doi.org/10.4271/2009-01-1111
5. Lee C-Y., Zhao H., Ma T., "Analysis of a novel mild air hybrid engine technology, RegenEBD, for buses and commercial vehicles", International Journal of Engine Research Vol. 13 Part 3, pp274-286 June 2012. (REF 2).
6. Lee C-Y., Zhao H., Ma T., "A Simple and Efficient Mild Air Hybrid Engine Concept and Its Performance Analysis", Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering Vol. 227(1):120-136, 2013. DOI: http://dx.doi.org/10.1177/0954407012454975

- EPSRC Grant on a Cost-Effective Regenerative Air Hybrid Powertrain, Hua Zhao and Tom Ma, £455,962, April, 2011- March, 2014.
- Research on Air Hybrid Engine, £15,000, Yuchai Machinery Ltd., Hua Zhao, 2010-2011.
- EPSRC Grant on Innovative Air Hybrid Engine Concepts for Next Generation Fuel Efficient Road Vehicles, £534,884, Hua Zhao and Tom Ma, 2007-2010.

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

Zhao's development of the mild air hybrid engine technology has been exploited by China's largest bus engine manufacturer, Yuchai. This company manufactures and sells 80% of the engines for city buses in China.

In October 2010, Brunel University and Yuchai successfully reached a commercial licence agreement and Yuchai made a £40,000 initial payment to manufacture and retrofit RegenEBD in buses in China plus loyalty payment.

The initial RegenEBD engine buses operated two city routes in 2011 and have demonstrated impressive fuel savings of between 4.7% and 10%, according to Yuchai. For the typical mileage of 45,000 km/year per vehicle, a 5-10% improvement in fuel consumption is equivalent to saving 1,100-2,200 litres of fuel and 3.6-7.2 tonnes of carbon per vehicle per year. Compared to other electric hybrid powertrain technologies, RegenEBD technology has proved to be much more cost effective in terms of manufacturing processes and fuel consumption.

Yuchai report that Prof Zhao's research has opened a new business opportunity for them. They have decided to re-align their manufacturing strategies and development efforts so that they can be ready for major manufacturing and retrofitting of RegenEBD engines in 2014. They have spent 3 years (2011-13) investing significant resources in the development and preparation for the

manufacturing of engines with RegenEBD. They have employed over 30 new engineers and purchased equipment for RegenEBD engine testing and bus operations in different cities. As is common in the automotive industry, the market introduction of such a significant new fuel saving technology requires robust engineering tests and evaluation. At the start of 2014, a few dozen vehicles will be manufactured with RegenEBD engines before significant production can commence.

Yuchai expects that hundreds of buses equipped with RegenEBD will be on the road within the next five years. Consequently, they are in the process of realigning their manufacturing and production process and business strategy to cater for this new product.

8 Patents have been filed for the air hybrid technology with 2 granted internationally and the other 6 pending. RegenEBD won the Low Carbon Vehicle Technology Challenge Award in 2009.

The technology was presented at the London Low Carbon Vehicle and the SAE Congress and Commercial Vehicle Conferences in 2010, 2011, and 2012, and also at the 2012 FISITA World Automotive Congress, where it was selected as one of the 3 projects for the Islands of Excellence Award.

Between 2009 and 2013 Brunel explored opportunities with several OEMs and Tier 1 suppliers in the UK and overseas and has subsequently entered into a development programme with a UK SME partner, PTech, to apply the technology to the UK and European bus retrofit sector. Collaborating with a bus retrofit company, and securing £130k of TSB funding, PTech is working on the retrofit engineering design, testing, and optimisation, exactly as has been the case with Yuchai. This application will be trialled on UK buses at the start of 2014.

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

1. A supporting letter has been received by the Chief Engineer at Guangxi Yuchai Machinery Company, China. All information regarding the performance of RegenEBD and the company's re-alignment of their business strategies has been provided by the contact.
2. Additionally, the Director at PTech (Powertrain Technologies Ltd), Norfolk, can be contacted for their plan to retrofit RegenEBD in the future.