Institution: BRUNEL UNIVERSITY (H0113)

Unit of Assessment: 15 – General Engineering

Title of case study: Ultra-precision Micro Milling for High Value Manufacturing

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

The UltraMill machine was developed at Brunel University in 2008, in collaboration with Ultra Precision Motion (UPM) Ltd, to help support UK and European manufacturing SMEs in high value manufacturing sectors, particularly in ultra-precision and micro manufacturing. The machine has a novel design and the sub-systems and machine elements have a number of technological innovations. Two international patents have been granted to protect the IP within the machine. A surface roughness of 4-6 nm was micro-milled on non-ferrous metal components by the UltraMill in 2008, which at the time was the finest engineering surface achieved by ultra-precision micro-milling in the world.

A licence agreement was signed with ITP Group (UK) in 2012 for the commercial production of the UltraMill. This was ITP's first entry into the high-precision milling market. ITP realigned their production systems to begin manufacturing the UltraMill in late 2012 and have manufactured 3 machines to date.

Contour Fine Tooling, which leads the worldwide market in the field of diamond cutting tools, was inspired by the UltraMill, and developed the first diamond micro-milling tool in the world. The UltraMill was used to test the tool's capabilities and feasibility; the new tool has since been successfully sold. It is now being used to manufacture a number of high-value products. In particular it is used by Apple to produce the bevelled edges of the iPhone 5S. Apple currently manufactures 150,000 iPhone 5S units per day.

2. Underpinning research (indicative maximum 500 words)

The UltraMill machine was developed through the EU FP6 MASMICRO Integrated Project (2004-2008), to help support UK and European manufacturing SMEs in high-value manufacturing sectors, particularly in ultra-precision and micro manufacturing. Substantial research was undertaken by Professor Kai Cheng and his team in Advanced Manufacturing and Enterprise Engineering (AMEE) at Brunel University during the machine research and development phase, and further commercial exploration occurred particularly in the period of 2008-2012 [1][2][3].

The UltraMill is a bench-top micro-milling machine designed and built to perform the milling, drilling and grinding of a wide range of miniature components as well as fine surface features on components of up to 150x150x80 mm in size. Its unique construction, using air bearings and direct drives on all axes, means that it can achieve outstanding dimensional precision, surface geometry and the finest surface roughness. This is achieved by the machine's multi-scale simulation-based design and analysis, combined with its novel design structure, with sub-systems and elements that incorporate a number of technological innovations.

Machining trials on soft metal substrates produced surface finishes down to 10 nm Ra, with surface flatness or straightness better than 0.1 μm over 50 mm of travel and repeatability of less than 1 μm, making it suitable for the machining of complex optical components or their moulds [4][5].

The UltraMill machine has the following further special technical features and capabilities, developed through the underpinning research and development at Brunel University:

- Aerostatic bearings incorporating squeeze film dampers and direct drive motors on all linear and one rotational axes so as to achieve smooth motion with exceptional accuracy and excellent dynamic performance;
- High speed aerostatic spindles capable of 200,000 rpm offering the highest machining efficiency for micro milling;
- PC based CNC control system with Windows platform and customizable HMI and bespoke micro milling capability;
- Optional extras include a robot-based tool/workpiece change and inspection subsystem

and a condition monitoring subsystem.

Applications of the UltraMill machine include high precision mould tools, optical components, medical devices, transducers, watch components, micro printed circuit boards, electronic components and tribological components

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

(1) D. Huo, K. Cheng and F. Wardle (2010) Design of a 5-Axis Ultraprecision Micro Milling Machine – UltraMill: Part 1: Holistic Design Approach, Design Considerations, and Specifications, *International Journal of Advanced Manufacturing Technology*, 47, pp.867-877. http://dx.doi.org/10.1007/s00170-009-2128-2

(2) Frank P. Wardle, C. Bond, C. Wilson, K. Cheng and D. Huo (2010) Dynamic characteristics of a direct-drive air-bearing slide system with squeeze film damping, *International Journal of Advanced Manufacturing Technology*, 47, pp.911-918.http://dx.doi.org/10.1007/s00170-009-2139-z

(3) D. Huo, K. Cheng and F. Wardle (2010) A holistic integrated dynamic design and modelling approach applied to the development of ultraprecision micro-milling machines. *International Journal of Machine Tools and Manufacture*, 50(4), pp.335-343 http://dx.doi.org/10.1016/j.ijmachtools.2009.10.009

(4) X. Z. Sun and K. Cheng (2010) Multi-scale simulation of the nanometric cutting process, *International Journal of Advanced Manufacturing Technology*, Vol. 47, pp. 891-901. http://dx.doi.org/10.1007/s00170-009-2125-5

(5) D. Huo and K. Cheng. (2010) Experimental investigation on micromilling of oxygen-free, high-conductivity copper using tungsten carbide, chemistry vapour deposition, and single-crystal diamond micro tools. *Proceedings of the IMechE, Part B: Journal of Engineering Manufacture*, 224(B6), pp.995-1003. http://dx.doi.org/10.1243/09544054JEM1828SC

Key research grants achieved by Professor Kai Cheng and his research team (AMEE) in the area of ultra-precision and micro manufacturing are as follows (2008-2013):

- Kai Cheng, Self-learning control of tool temperature in cutting processes (ConTemp), EU 7th Framework NMP call (Contract no. FP7-NMP-2008-SMALL-2-228585), 1st November 2009 – 31st October 2012, £385k.
- Atanas Ivanov and Kai Cheng, Development of a next generation micro-ECM sinking machine for the automotive, aerospace, and medical device sectors (µECM), EU 7th Framework NMP call (Contract no. FP7-NMP-2010-262072), 1st October 2010 – 30th September 2012, £402k.
- Kai Cheng, Richard Rakowski and Ben Jones, Smart and effective engineering manufacturing (SEEM), Technology Strategy Board (Contract no. BD266E), 1st November 2009 – 31st January 2013, £195k.
- Atanas Ivanov and Kai Cheng, Minimizing defects in micro-manufacturing applications (MIDEMMA), EU 7th Framework NMP call (Contract no. FP7-NMP-2010-285614), 1st October 2011 – 30th September 2014, £310k.
- Kai Cheng, Atanas Ivanov and Richard Bateman, Development of the functional surface µ-texturing module with application to micromilling: design, analysis, performance testing and applications, Industrial project with Korean Institute of Machinery and Materials (funded by Korean Government), 1st July 2011 – 30th June 2016, £190k.
- Kai Cheng and Richard Rakowski, Development of Smart Drilling Spindle Systems, KTP Program with Westwind Ltd – GSI Group, Technology Strategy Board (Contract No. KTP009277), 1st September 2013 – 31st August 2015, £150k.

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

The UltraMill machine was developed to support the engagement of UK and European manufacturing SMEs in high value manufacturing, particularly in ultra-precision and micro manufacturing. UPM Ltd., who built the first machine with Brunel University in 2008, have sold the

licence for the commercialisation and manufacturing rights to ITP Ltd for a 2% share of the sales of the machine.

Figure 1 UltraMill

In early 2013 ITP manufactured the first batch of 3 machines and sold them to Germany (*Sonplas GmbH)*, China and the UK. *Sonplas GmbH(Germany)* is a leading international manufacturer of fuel injection devices, who purchased their UltraMill to manufacture new injectors for diesel engines.

The development of the UltraMill has created economic, technological and employment benefits up and down the supply chain. In particular, a number of UK manufacturing companies have benefited from the UltraMill by supplying parts and components for its manufacture. These include Renishaw, who supplied the encoders, Delta Tau UK (the controllers) and Spar-Tec Industries Ltd (the machine guard).

During the development of the UltraMIll, a number of industrial companies benefited from ultra-precision machining services. These included Contour Fine Tooling (2008), Rainford (2010) in the UK, and Aplix 2008/9. Contour Fine Tooling (CFT) leads the worldwide market in diamond cutting tools, holding 30% of the market share. Before they had become known for their cutting-edge diamond cutting tools, they manufactured and sold diamond turning tools. However, inspired by the concept of the UltraMill, they developed the first diamond micro-milling tool in the world, using the UltraMill as a test-bed to demonstrate the feasibility of their prototype before introducing it to the market.

Figure 2 iPhone 5S

CFT successfully marketed the diamond micro-milling tools; following their lead, diamond micro-milling technologies are now available from 4 companies in the world.

CFT's diamond micro-milling technology has been used for the bevelled edges of the iPhone 5S. 23 million units of the iPhone 5S were sold since its release and Apple currently manufacture 150,000 units per day. (Daily Mail 15 Oct 2013)

Following on from the UltraMill, TSB-funded research and development helped build a new smart cutting tool, which can monitor the micro-milling process by measuring the cutting forces in real time. This tool contains a number of technological innovations and has attracted commercialisation interest from Renishaw. Two international patents have been granted on the design of the tool (August 2013) and the magnetic squeeze film damper for air bearings (January 2008).

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

Contactable:

1. Managing director, UPM Ltd, UK
2. General Manager - Contour Fine Tooling Ltd, Hertfordshire
3. Managing director, Delta Tau (UK) Limited

The development of the UltraMIll machine had led to substantial commercial and business benefits to the industrial companies in the joint machine development and the machine building supply chain. For instance, this is well evidenced by the strong claims by two industrial partner companies (UPM Ltd and Delta Tau UK Ltd) at their websites:

- UPM Ltd: http://www.upm.org.uk/UltraMill
- Delta Tau UK Ltd: http://www.deltatau.co.uk/brunel.html