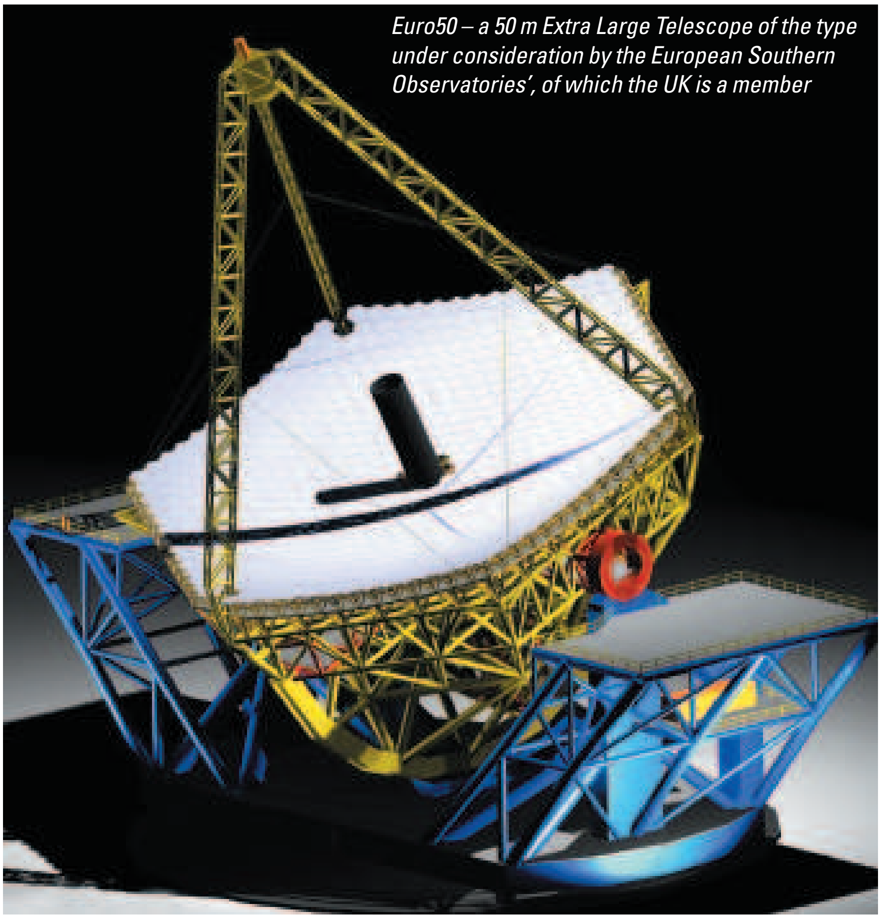
Big science drives innovation

Long-term science-led machine tool and process development for optics production now finds the UK in a position to exploit a number of growing markets worldwide. Andrew Allcock reports

A partnership between two eminent UK research centres has realised new, advanced machine tools that are set to re-establish UK manufacturing capability of large ultra-precision surfaces. They will support the delivery of the large number of mirror segments required for tomorrow's so-called Extra Large Telescopes (ELTs) via a productionised manufacturing process.

Three new machine tools have been developed with £4.2 million funding provided under the Research Council's UK Basic Technologies programme. The machines will establish a unique 'manufacturing chain' offering rapid manufacturing of large surfaces at nanometric levels of precision. This manufacturing chain will be housed at the state-of-the-art Technium OpTIC building in North Wales and provide the UK with a national manufacturing facility.



Euro50 – a 50 m Extra Large Telescope of the type under consideration by the European Southern Observatories', of which the UK is a member

Opened in February 2005, OpTIC is a £15.7 million project backed with over £6.3 million of European Objective 1 funding provided through the Welsh European Funding Office (WEFO), part of the Welsh Assembly Government. (*www.wda.co.uk* – search for 'optic').

The so-called Ultra Precision Surfaces project, known simply as 'UPS', is driven by Dr David Walker of University College London's Optical Sciences Laboratory and Professor Paul Shore of the Cranfield University Precision Engineering centre.

Dr Walker set up UCL Optical Sciences laboratory in 1985 (see also page 25) and he is the technical director of Zeeko, a UCL spin-out machine tool company established in 2000 by Dr Walker and Richard Freeman, ex-managing director of Taylor Hobson.

Professor Shore, who now heads the Cranfield University Precision Engineering centre, is a machine tool developer. He has been a technical director with SKF and Lidköping Machine Tools, in Sweden, and earlier a technical manager at the Cranfield Unit for Precision Engineering (CUPE). His Swedish work experience gives him detailed understanding of mass production grinding machines and his Cranfield activities gives him expertise in ultra-precision fabrication.

Professor Shore is also the instigator of the UK Precision Engineering Network (*www.ukpen.co.org*) established in 2003. Its target is 'hard manufacturing technology'; it is not a talking shop about current research, but a forum to suggest

what the UK should be researching and developing. UK PEN played an important role in bringing together the partners in the Technium OpTIC.

The UPS-developed ultra-precision machine tools are:

- Cranfield's BoX™, an ultra-precision grinding and measuring machine capable of machining 2 m diameter parts that is being launched at MACH 2006 (Stand 5050 – see also page 22);

- Zeeko IRP 1200, an ultra-precision polishing machine developed by Zeeko which features three discrete processes – a free abrasive polishing method; 'grolishing', a fixed abrasive polishing method; and a fluid jet polishing technique (see also page 25) – this follows BoX grinding in the process chain;

- RAP1000, an ultra-precision Re-active Atom Plasma system that is being developed by Cranfield University and a California-based SME, RAPT Industries. In the RAP process, an inductively coupled plasma torch and re-active gases perform local material etching with nanometre levels of control. This allows the final 'figuring' of the material surface;

In addition to the UPS-developed machines, a 1 m profilometer built by NPL under the National Length programme will also join this hardware at Technium OpTIC and will support measurement of the manufactured surfaces.

The driving 'big science' demand for

such advanced machine tools is the detection of earth-like planets close to far-away stars or 'exo-planet detection'. In basic terms, in order to detect earth-like (dim) planets that are located close to far-away (bright) stars, astronomers need bigger 'eyes' (larger telescopes). Today's largest telescopes are 10 m in diameter, for example the Keck telescopes (*www.keckobservatory.org*). The primary mirrors of the Keck telescope are made from approximately 36-off, 1 m size hexagonal segments. In fact, Cranfield delivered its OAGM 2500, 2.5 m capacity optic grinding machine to Eastman Kodak in 1989 for the grinding of the 1 m segments employed in the two 10.2 m Keck telescopes. But in total, each segment took many hundreds of hours to achieve the required form accuracy of 30 nm (0.00003 mm).

In the last six years, astronomers have proposed ELTs of 30-100 m diameter, demanding many 100s, even 1,000s, of 1 m sized mirror segments. The Euro50 is just such a telescope (picture, page 20). In order to realise an ELT by the European Southern Observatory's target date of 2015 (*www.eso.org*) it was clear to Dr Walker

Cranfield University's BoX

The go ahead for Cranfield University's ultra-precision grinder, BoX™ (Big OptiX), was given in April 2004 and the project kicked off in June that year. Machine build started in November last year. It had been expected that the machine would be a scaled up version of the Cranfield Tetraform grinder (see *Machinery*, 18 June 2004, page 20), but the structure was found to be unscaleable.

Commercial company Cranfield Precision was contracted to support the design of the new University-patented BoX concept – the University's structural and dynamics expertise underpinned this.

Dynamic stiffness has been at the root of the machine's design, because any vibration when grinding ceramic mirror segments would damage the surface. The machine's first resonant frequency is greater than 100 Hz – "there is no machine of this capacity that can claim such a high figure, which means we can grind 10 times faster," says Paul Morantz of Cranfield University. Minimum moving mass is the other requirement and Cranfield Precision senior designer Roger Read is credited with major design input leading to low moving masses while maintaining the required high stiffness.

The resulting structure sees a spindle head carriage driven in x by two linear motors along hydrostatic guideways located above a 1.2 m diameter hydrostatic rotary table. The centre of the 20°-from-vertical grinding spindle passes through the table's centre. It is essentially a portal design with cast iron structures mounted on a granite/resin base. The 17 tonne machine can grind objects up to 2 m diameter.

Various elements of the machine are cooled by separate circuits with fluid kept at ±0.1 °C; some 10 kW of heat is 'dumped' outside a ±1 °C temperature-controlled manufacturing area. The machine is symmetrical about two planes: "so any errors will be more systematic and affect both sides equally," says Professor Shore.

The specification that the machine must satisfy is that for 1 m parts it must have a form accuracy of 0.001 mm peak to valley. Basically, the form factor error must be better than one part in 10^6. In the event, Cranfield believes the vertical accuracy could be up to a factor of 10 better. Rotation of the table is accurate to within 0.01 arc seconds. The z- and x-axis linear motions use 1 nanometre resolution position encoders.

Importantly, the machine includes an independent, unstressed measuring frame to provide a post-process measurement capability. The machine features a spindle-head-mounted probe located on an Invar rod slideway having a near-zero coefficient of expansion.

The probe is connected to a laser interferometer which references a static straight edge made of zero-coefficient-of-expansion material above the spindle carriage. Probe measurement in x makes use of the machine's axis measurement. The result is that the BoX machine is more accurate than a CMM! Much of the machine is UK made and full details will be available on stand 5050 at MACH 2006.

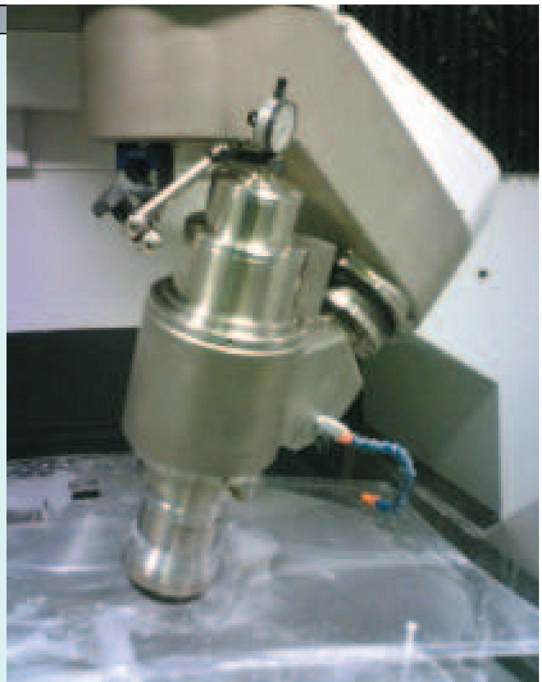
Dr David Walker, UCL and Zeeko

The UCL's polishing machinery activities commenced under Dr Walker in the 1980s when the university acquired large optical production and test equipment for parts up to 2.5 m in diameter following the closure of Sir Howard Grubb Parsons, Newcastle, the UK manufacturer of telescopes used by the science community.

From the mid-1980s, UCL started a programme of research into computer-controlled optics polishing under Science and Engineering Research Council funding. In 1994, it built a rudimentary computer-controlled polishing machine for a company in Taiwan. At that time there were no such machines on the market, although some optics manufacturers were developing their own in-house processes.

In 1994, UCL realised that there was a substantial market for computer-controlled polishing machines, says Dr Walker, and a company was established with a DTI SMART 1 award – Optical Generics Ltd, now Optical Investments Ltd, the holder of key process patents. An initial joint venture in 1998 failed to work out, but in 2000 Dr Walker and Mr Freeman set up Zeeko.

In the early days, the company cohabited with CMM maker Ely Metrology before moving to a further shared home on Hermitage Industrial Estate, Coalville, Leicestershire, and subsequently to its own premises on the same estate in January this year. And at the end of this February, the company was just putting the finishing touches to the 1.2 m diameter capacity machine destined for the Technium OpTIC. This replaces an existing 1.2 m machine being shipped to China. The Technium also boasts 600 mm and 200 mm capacity Zeeko machines.



The two key patents of the Zeeko process (above) are the inflatable, balloon-like tool (bonnet) that allows for control of both contact pressure and contact area independently, and the precession motion of the tool. A perfect Gaussian removal profile results. The patent also applies to non-contact processes, such as a fluid jet – useful for polishing sharp internal corners. A third element in the process is the software that drives it to remove errors of form in an iterative 'estimate-polish-measure-adjust' manner (taking in pressure, contact area and time) which is superior to existing approaches. And apart from polishing, the process of 'grolishing' has also been developed – a combination of grinding and polishing for more aggressive removal rates that allows for the use of a relatively inaccurate grinding machine prior to polishing

and Professor Shore that a more efficient method of manufacturing large ultra-precision mirror segments was required.

To slash mirror segment manufacturing time from 100s to 10s of hours, clearly an improvement in the manufacturing speed by a factor of 10 would be required; but a complete manufacturing process must be proved before committing to the European Southern Observatories' ELT project, capable of producing parts accurate to within 1 part in 10^8.

To study production methods for volume manufacture of large optics, a small DTI-supported investigation was proposed by Professor Shore together with Phil Parr-Burman of United Kingdom Astronomy Technology Centre (UKATC) and Dave Rimmer, then a director with Thales Optics (now Qioptiq). The so-called Large Optics Manufacturing Study (LOMS), a six-month, £60,000 activity, kicked off in October 2002, bringing together relevant UK experts at UCL/Zeeko, Cranfield University, Technium OpTIC, UKATC and NPL (for measurement). LOMS provided the basis for the Basic Technologies UPS project driven by Dr Walker and Professor Shore plus the UKATC, with resulting technology hosted by Technium OpTIC (whose managing director is now Mr Rimmer). The total project budget is £4.2 million and sets out to develop technology for industrial scale, economic production of 1 m aspheric mirror segments for ELTs.

The facility at the Technium OpTIC is expected to be completed by the middle of next year when the Cranfield RAP machine arrives. "We will be the best equipped laboratory for process development of 1 m-scale optics in Europe," Dr Walker claims.

In addition to the specific ELT target, however, market research shows that the available production capacity for medium scale optics (40 cm to 1 m) for astronomy, defence, space and laser will be "vastly oversubscribed" in coming years, according to the Zeeko director, and it is intended to set up a separate business from Zeeko within the Technium OpTIC to manufacture such optics. Already it has received its first order for a 60 cm lens for an American company – $80,000 – with support provided by Zeeko personnel.

Elsewhere, the US company would have been quoted 8 to 12 months but might have waited 16 months, says Dr Walker. "By combining technologies, we will take many months out of that, while in parallel Zeeko will learn a lot about processes, allowing it to improve its technology further," he says.

However, while highly polished, form-precise optics/mirrors for astronomy has been the main theme over several years and continues to be so, it turns out today that there are many other applications out there waiting for the technology. For example, there is a need for highest quality optics to support the photolithography used in the production of the narrowest of microprocessor circuit tracks, and for polished turbine blades.

And preliminary results from a recently concluded two-year Engineering and Physical Science Research Council/MoD-funded research project, undertaken between Dr Walker and Huddersfield University's Professor Liam Blunt, show that the life of an artificial knee joint can be significantly extended through better polishing of joint faces.

Zeeko is already commercially successful, though. To date, since the first, privately-funded Zeeko machine – a 200 mm diameter optic capacity unit – was shown at a conference at UCL in May 2000, the company has manufactured: 17-off 200 mm capacity machines (including five made by licensee Satis Loh, Germany); two-off 400 mm (a third in build); two-off 600 mm; one-off 1.2 m (a second in build); and there is also an 800 mm machine currently in build.

In addition to actual machine tools, Zeeko processes (including 'grolishing') and software have been retrofitted to a 3.5 m capacity machine frame at telescope maker Brashear, California, USA, demonstrating process scaleability.

Cranfield University Precision Engineering likewise designs and builds optics manufacturing machine tools for both research and commercial use, as it has done since its inception in 1968. Much of its work is 'under the radar' and commercially confidential, however. In 1987, a spin-out company, Cranfield Precision Engineering (now called Cranfield Precision and owned by Cinetic Landis Grinding, Keighley, itself owned now by French firm Groupe Fives-Lille) was created out of this activity.

Cranfield University Precision Engineering plans to exploit its BoX concept commercially; trademarks and patents have already been secured.□