NPL
National Physical Laboratory

Engineering *Precisely*

A National Measurement Newsletter

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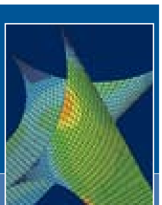

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Department for **Innovation, Universities** & **Skills**

Groundbreaking science behind land-speed record bid

Scientists at NPL have worked with the Atomic Weapons Establishment (AWE) and Fluid Gravity Engineering (FGE) to advise a land speed record bid team on two of the most high-risk aspects of the world record attempt – wheel and rocket designs.

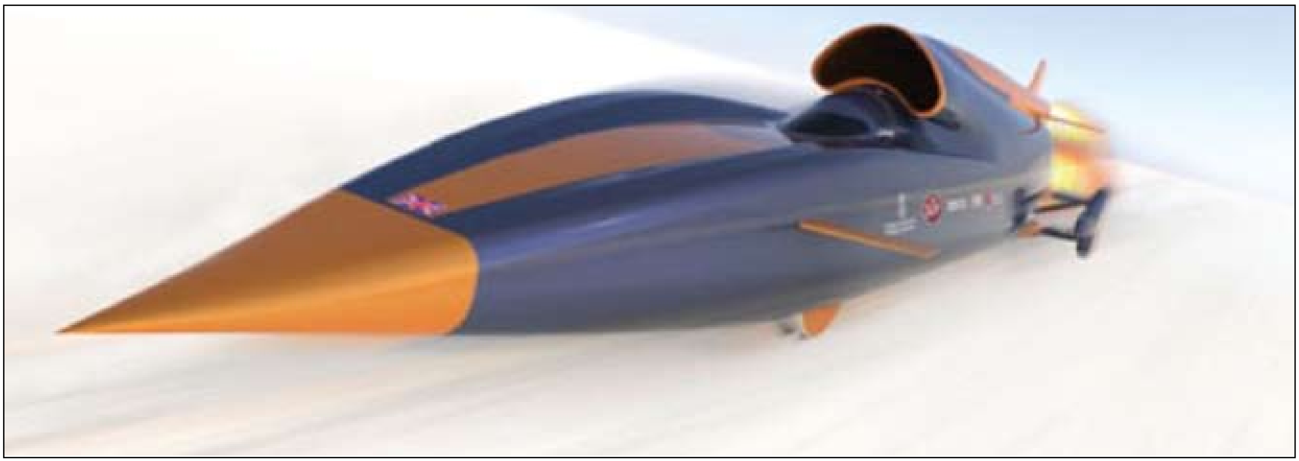

Image courtesy of Curventa

Scientists at NPL have worked with the Atomic Weapons Establishment (AWE) and Fluid Gravity Engineering (FGE) to advise a land speed record bid team on two of the most high-risk aspects of the world record attempt – wheel and rocket designs.

Andy Green, the current world record holder and first man to drive a supersonic vehicle on land, and Richard Noble, Head of the Design Team (and former world record holder), aim to develop the first land speed vehicle that breaks the 1,000 mph barrier.

The BLOODHOUND Project founder sponsors:

- Swansea University
- Serco Plc
- Engineering and Physical Sciences Research Council
- University of the West of England
- STP

This project, 'BLOODHOUND', will have its design underpinned through world-class research from some of the UK's top laboratories.

To reach 1,000 mph the wheels must be able to rotate at 10,500 rpm without being damaged by the surface or any stones that they run over. They also need to be as light as possible to minimise steering and suspension forces, and they must be capable of absorbing all of the weight, down force loads and stresses and distribute this pressure without causing damage to the vehicle or the surface.

NPL has spent the last year examining every aspect of the wheel design. NPL materials

The BLOODHOUND Project product sponsors:

- Ashford Fabrications
- Airborne Systems
- Brixx Solutions
- Curventa Design Works
- The Engineering and Technology Board
- Falcon project
- Instrumentel
- The Mathworks
- MCT (Menard Competition Technologies)
- Ministry of Defence
- National Physical Laboratory
- Parker Hannifin Ltd
- PDS Engineering
- Royal Academy of Engineering
- Servo Interconnect Ltd
- Siemens PLM Software
- Tool Design & Manufacture (Yate) Ltd
- IN2 Swansea University
- The Tourism Company
- Out of Hand Ltd
- Newburgh Engineering Co Ltd
- Visioneering Ltd
- Goodridge (UK) Ltd
- Faro UK
- Advanced Fuel Systems Limited
- Andrews Precision
- Diamond Point Embedded Computing

experts researched the choice of metals and composites that could be used in the design, providing reports on titanium and aluminium alloys, and metal composites. This will help to advise the team on what materials are most compatible with the wheel size, brake and suspension requirements. NPL also worked with AWE and FGE in considering the effect that shockwaves would have on the wheel design, and advised on the best way to manufacture the wheels.

The vehicle will have the first ever mixed powerplant of a hybrid rocket motor and a jet engine. It uses cutting edge jet technology to provide the initial thrust and the novel rocket impulse to achieve the 1,000 mph target.

NPL and FGE developed a modelling tool to understand the hybrid combustion process and simulate the internal motor ballistics. The data generated has the potential to help optimise the injector design, oxidiser streams into the fuel grain, radiation transfer, regression rates and rocket motor exhaust. NPL also provided advice on the type of materials to be used in the rocket design, how high temperatures would affect them, what the best material would be for rocket nozzles and how all of these should be produced.

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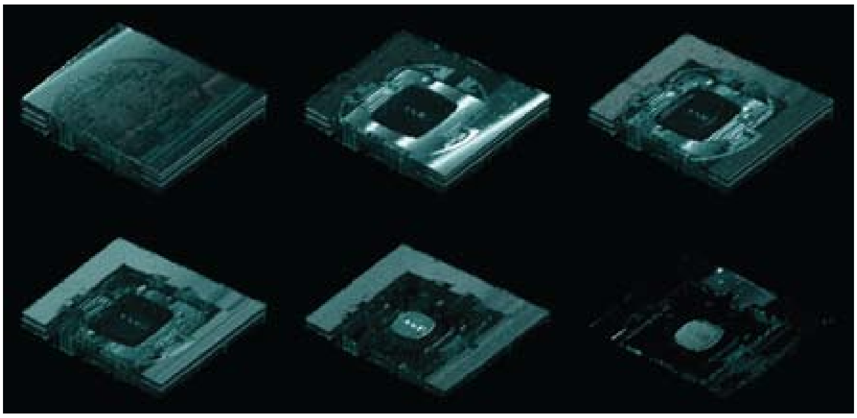
Below the surface

NPL have won a project aimed at developing 3D techniques for the measurement and characterisation of MEMS (Micro Electro-Mechanical System) devices.

Within the semiconductor and MEMS industries there is a requirement for a non-contact, single-sided method for measuring the thickness of layers within devices. The MEMS industry needs to image the internal structure of devices to enable the measurement of critical dimensions and identify defects. An example is a MEMS pressure sensor, which relies on the successful formation of an etched diaphragm, the thickness and quality of which is fundamental to the performance of the sensor.

This project is funded by DIUS's (Department for Innovation, Universities and Skills) Measurement for Innovators programme, involving four industrial partners: Michelson Diagnostics, QinetiQ, GE Sensing and Olympus. The project will focus on two techniques, OCT (Optical Coherence Tomography) and IR confocal microscopy.



OCT images of a MEMS pressure sensor revealing the internal structure, taken using Michelson Diagnostics EX1301

Work at NPL has already demonstrated the suitability of the OCT in imaging silicon MEMS sensors using the Michelson EX1301. This project will aim to determine the overall accuracy and establish traceability for each technique in measuring a selection of MEMS devices.

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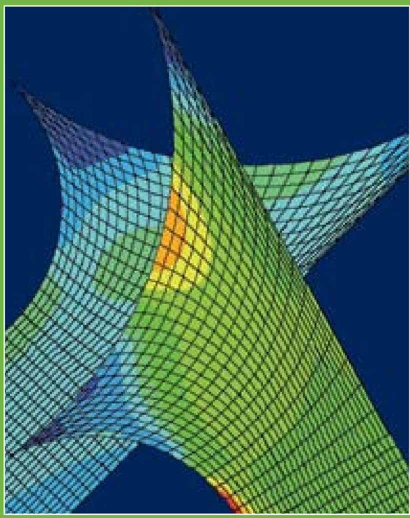
To find out more about the Measurement for Innovators programme, please visit
www.npl.co.uk/mfi

Modelling long-term creep behaviour of plastics for design

NPL has developed a model that better describes the long-term deformation behaviour of plastics, which will help industry meet the increased need for reliable lifetime predictions for plastics materials.



Plastics are increasingly being used in applications where prediction of their long-term performance is an important design consideration. Finite element (FE) analysis, widely used in many industrial sectors, can be used to calculate stress and strain distributions within a component under service loads, as well as any dimensional changes. Polymeric materials are viscoelastic, so properties change with time when under load. A predictive model must therefore take proper account of time-dependent material properties. It turns out that relevant material properties for a long-term stress analysis are obtained from creep tests. The accuracy of predictions depends on a number of factors including the type of material model used to describe creep behaviour. The creep models currently available in FE systems are generally only suitable for low-stress applications where deformation behaviour is linear. Non-linear creep is observed at moderate stress levels in short duration tests, but is also evident at lower stress levels in longer duration tests. Non-linear creep models in FE systems are based on time-dependent plasticity and are not applicable to plastics. NPL has therefore developed a model that better describes the long-term deformation behaviour of these complex materials. This will help industry meet the increased need for reliable lifetime predictions for plastics materials.

NPL measured pharmaceutical grades of poly(oxymethylene), and modelled the results using a creep function with four parameters. One of these parameters was found to decrease with increasing stress, and this gives rise to non-linear creep behaviour. NPL's measurements of creep under compression and shear have enabled the model to be adapted to include the influence of stress state.

In many applications stress is not simply constant with time. A viscoelastic theory is needed to predict deformation where some more general stress or strain history occurs. This is not straightforward when creep deformation is non-linear.

NPL scientists first generated an expression predicting the deformation under uniaxial tensile stress with an arbitrary stress/strain history. This has been coded as an excel-based macro and evaluated using experimental tests where the stress has increased or decreased in discrete steps. Solutions have also been obtained for the more complex situation of stresses changing under a specified strain history, for example constant strain (stress relaxation) and constant strain rate. In all cases very good agreement between predictions and experimental results have been obtained.

The theoretical expressions developed have also been extended to account for multiaxial stress states. This model has been coded into Abaqus by Bradford University (http://www.capps-help.bham.ac.uk/software/abaqus_6.4-1.htm). In the coming months the code will be evaluated by comparing predictions with experiment in tests where the stress varies throughout the specimen or subcomponent and, therefore, where creep rates vary with position, leading to the redistribution of stresses and strains.

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Laser TRACER to calibrate and verify coordinate measuring machines

NPL, with its partner PTB, has developed Laser TRACER - a new measurement system for high-speed, high accuracy calibration and verification of CMMs (coordinate measuring machines), CNC (computer numerical controlled) machine tools, and other leading-edge measurement applications. NPL is now able to bring standards laboratory level measurements to the shop floor, delivering significantly improved calibration times and minimum machine downtime.

Mounted inside the Laser TRACER is a fixed high-precision sphere with a form deviation of less than 50 nm, which serves as a reference reflector for an interferometer. This sphere is mechanically and thermally decoupled from the tracking mechanism, resulting in sub-micron stability during the movement of the tracking mechanism. This completely eliminates the guiding errors of the horizontal and vertical rotation axis, achieving centre of rotation stability better than 0.3 µm. The interferometer has a resolution of 1 nm at a maximum range of 6 m.

By locating the laser tube in the external control box with a fibre optic link to the Laser TRACER, the partners were able to produce a very compact design, with an added benefit of a greatly reduced thermal load.

The Laser TRACER is easier to use than traditional methods and produces on machine results extremely quickly. Its novel mechanical design and in-built data processing algorithm enable it to be used in a multitude of applications requiring high precision measurement of length, straightness, pitch, yaw and roll of all axes – all with sub-micron accuracy. The device requires very little thermal stabilisation prior to use, due to its in-built temperature and pressure compensation. Laser TRACER offers on machine calibration times of less than 3 hours, dramatically reducing the current 1.5 to 2 days period. This gives major productivity savings and reduces the cost of machine calibration/verification.

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New fixed-point for thermocouple calibrations

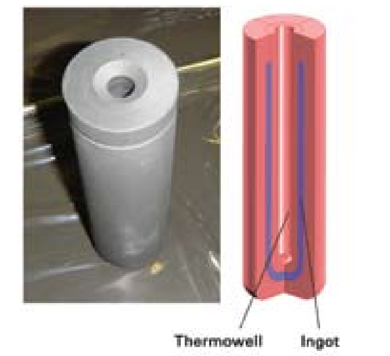
Metal-carbon (M-C) eutectic fixed points are revolutionising the practice of high temperature thermometry.

For thermocouples, the Co-C (cobalt-carbon) (1324 °C) and Pd-C (palladium-carbon) (1492 °C) fixed-points offer a step change improvement in calibration uncertainty, as well as providing the only means of calibrating Pt/Pd (platinum/palladium) thermocouples with fixed-points above the copper point (1084 °C). The Co-C fixed-point is now employed for routine thermocouple calibration, and is opening up new possibilities in industry. However, so far the mechanical robustness of the Pd-C fixed-point has proven problematic worldwide, with numerous breakages and widespread ingress of bulk Pd-C into the thermometer well, rapidly rendering the fixed-point unusable. These problems have been overcome, with NPL developing a Pd-C fixed point that is very robust and able to withstand many melt/freeze cycles.

In general, fixed-point crucibles that are employed as temperature standards are fabricated from extremely pure graphite. The design of the Pd-C crucible is conceptually similar to that employed for the Co-C fixed-point, which is already well established. For Pd-C fixed-points, the thermowell into which the thermocouple is inserted has much thicker walls than was required for the Co-C fixed-point - reducing the amount of Pd required to form the ingot. However, after several melt/freeze cycles of the Pd-C fixed-point, the graphite thermometer well and the alumina thermocouple protective sheath immersed in the thermowell become coated in Pd. The coating progressively accumulates as a function of time at high temperature. This is probably due to rapid migration of Pd, which has a high vapour pressure, from the ingot through the graphite thermowell, either as a vapour or by diffusion of the solid or liquid, or both. In addition, large density changes of the Pd-C over the operating temperature range result in large local forces on the graphite crucible, which is a common cause of breakage.

To construct the most robust possible crucible, a novel design of thermowell has been designed at NPL, with dual aims: firstly, the thermowell is more durable because it suppresses the propagation of cracks, strain, and shear, and secondly, it suppresses diffusion of Pd vapour from the ingot. This has resulted in a much more robust fixed-point which is free of the problems encountered with earlier designs.

The new fixed-point has been evaluated by performing repeated melt/freeze cycles with a Pt/Pd thermocouple inserted in the thermowell. The cycling included regular excursions to ambient temperature, approximately every 3 cycles, to emulate real-world calibration conditions. The repeatability of the thermocouple output at the melting point is 0.058 °C (95% confidence level) at 1492 °C. So far, nearly 70 melt/freeze cycles have been performed, and



Photograph of NPL Pd-C fixed-point crucible. Right: cut-away drawing of the same crucible

as yet no bulk fixed-point material has appeared in the thermowell, and no mechanical or structural problems have been encountered.

Currently, NPL is concentrating on a detailed evaluation of the metrological characteristics of this fixed-point, including the influence of heat flow along the thermocouple stem, and evaluation of the behaviour of crucibles where the thermowell is constructed from different materials. Early results are promising and the Pd-C fixed-point looks as though it will ultimately be suitable for routine calibration of thermocouples with ultra-low uncertainty at 1492 °C, complementing the existing Co-C fixed point at 1324 °C.

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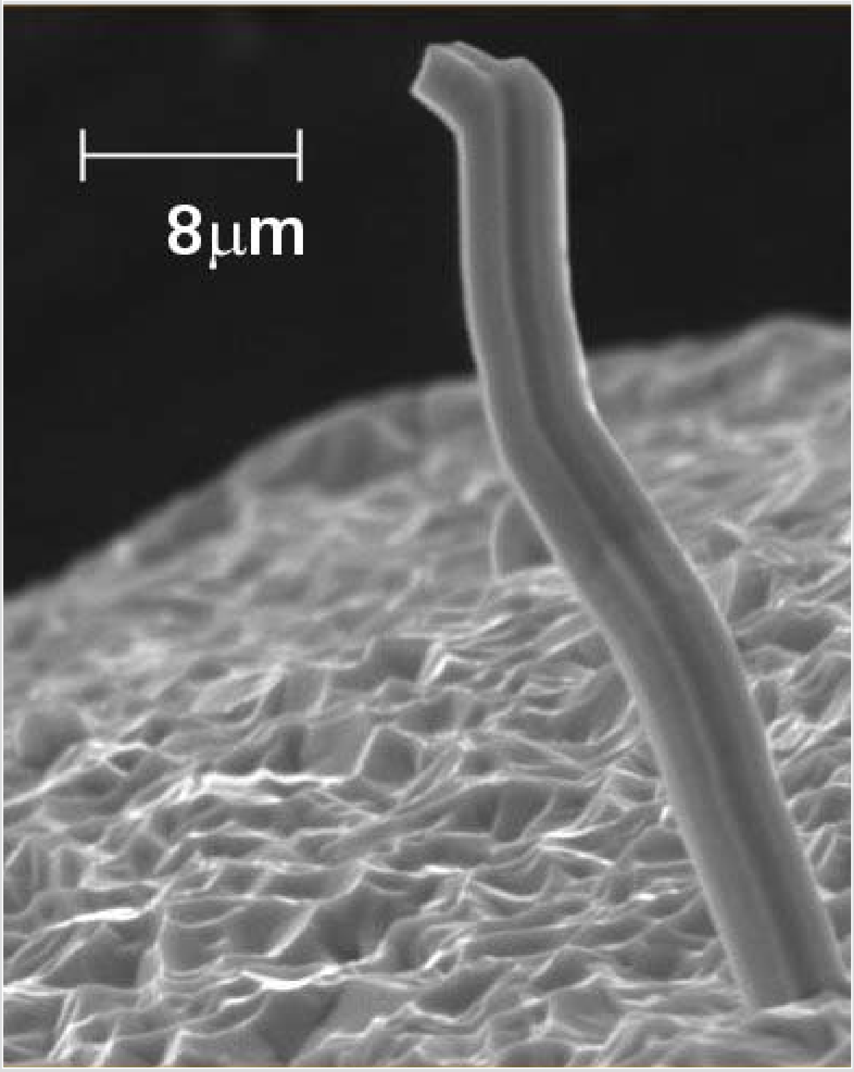
‘Tin pest’ control

NPL scientists to research ‘tin pest’ and ‘tin whiskers’ in lead free solder.

NPL has been using its expertise in the area of studying the allotropic phase transformation in tin and its alloys, commonly known as tin pest, to measure the implications of adopting lead free solder manufacturing practices. NPL has just received funding and is committed to co-fund this work with industry support, and has allocated a budget over a two-year period to research the problem of tin pest. NPL are looking for further industrial partners and are keen to hear from interested companies.

Tin pest can decompose tin into powder at low temperatures. Tin pest was thought to be a problem of the past, as tin lead alloys did not suffer the same effect. Yet the Restriction of Hazardous Substances Directive (RoHS) bans most uses of lead and the problem has returned, as lead-free alloys contain 95% to 99% tin. Tin pest could dangerously affect the safety and functionality of electronic products used across many manufacturing sectors, such as the avionics industry.



A tin whisker

RoHS has also seen electronics component manufacturers moving to pure tin component termination finishes. These are prone to the spontaneous growth of ‘tin whiskers’, which can cause catastrophic failures in electronic circuits. Reported failures include the loss of at least two communications satellites and the unplanned shut down of a nuclear reactor. It has been suggested that conformal coatings (materials applied in thin layers, often by dipping, spraying or flow coating) can be used to inhibit whisker growth.

NPL has developed a new measurement system and test method to assess the ability of different conformal coatings to stop or slow down tin whisker growth. The method also can help conformal coating developers to modify their coatings to inhibit whisker initiation, growth and penetration for electronic circuits.

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In-line blades

The National Physical Laboratory (NPL) recently completed a consultancy to identify a suitable measurement system for the oscillating movement of a razor blade used to slice medical biopsies. Out of plane movement of the blade can damage the membranes and biopsies being sliced, so accurate measurement of the blade is critical to the system's use. NPL has put forward a design solution and verified its effectiveness.

A medical instrument company has designed a new device with an adjustable blade, which oscillates at a range of frequencies. It is used to cut samples from medical biopsies for analysis. The alignment and movement of this blade is critical to the instrument, and misalignment can cause the blade to move out of plane, especially at the higher frequencies, damaging the cells to be analysed. The designers required consultancy on a method to measure the error in movement of the edge of the blade to allow for better alignment by the user.

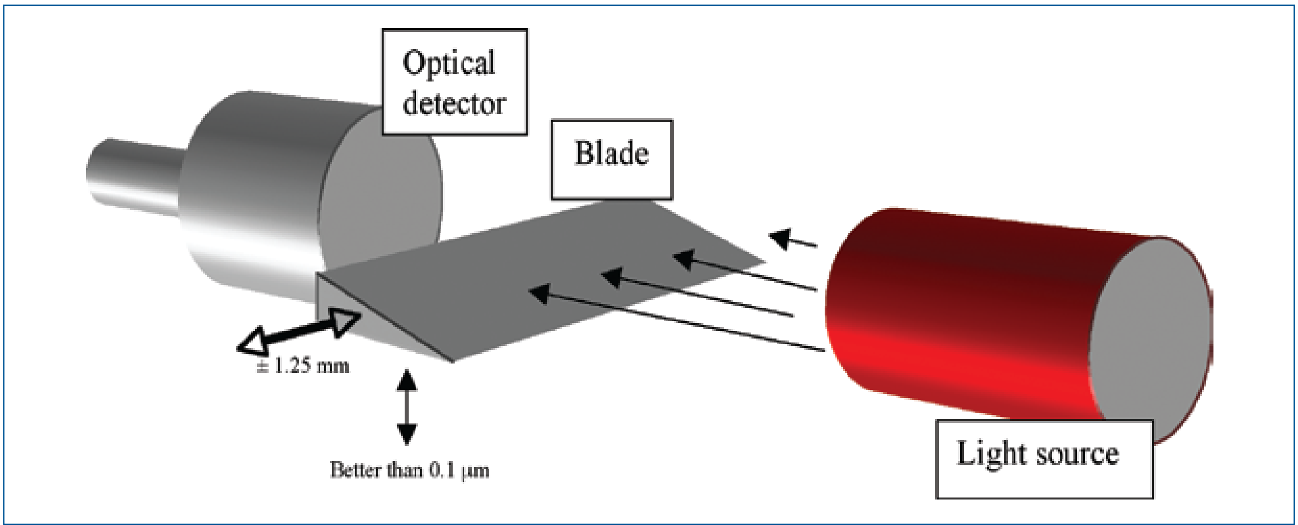
NPL devised an optical system to solve this measurement problem. The idea was to use a light source shining over the blade, which would then be detected by an optical sensor behind - with any deviation in the blade varying the amount of light and intensity measured by the sensor.

NPL built a test rig for this method. An oscilloscope was used to measure the output of the light sensor, and a stage micrometer was used to move a blade across the beam of light at controlled, 10 µm steps, to devise a change in the sensor output as a function of the blade position. The point at which the beam is only half exposed to the sensor is the most sensitive to movement and is therefore the crucial zone.

The limits of the sensor and set up were tested through a series of experiments. It was possible to identify the resolution of the sensor voltage output and the effective change in light to this system when a blade is moving through the beam.

This test work demonstrated that the principle will be effective and should be sufficient to measure changes of less than 0.00005 V, and so, based on the results found, should theoretically meet the required accuracy of 0.1 µm.

The four-day consultancy allowed the company to evaluate a method for measuring the error in their instrument's blade movement. This movement is critical to the use of the device and NPL's work has helped provide the company with understanding of key areas to consider when developing a system to measure and help adjust for this movement. It also provided them with detailed information and data on a suitable system for doing this, its limitations, and where to source the required



Theoretical system setup

Image courtesy: istock photo

components. Following on from this research the company has now incorporated this system, in principle, into their production design for the blade movement metrology device, leading to a large improvement to their instrument and will hopefully lead to improved outcomes for patients, thanks to the analysis of more accurate biopsy samples.

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NPL dimensional training is on another level

Dawson Precision Components (DPC) requisitioned NPL Level 1 dimensional training for some of its personnel. Finding the training to be of great benefit, DPC plans to roll-out Level 1 training throughout its workforce and advance key personnel through Level 2 training.

DPC has a range of skills across its workforce as wide as the bespoke products it develops for its customers. Its operators are all from different backgrounds with varying levels of experience - from full apprenticeships to in-house on the job training. They have differing levels of understanding with regard to technical drawings and the use of measuring equipment.

DPC invested in NPL Training to bring all these employees up to an across-the-board level of competence. The course demonstrated that the simplest way of measuring a particular feature is not always possible due to reasons such as feature size and accessibility. As a result, employees learnt to consider the inaccuracies of the measuring equipment they use, even when operating the most advanced instruments on the market.

The benefits that the operators came away with include a clearer understanding of geometric symbols and tolerances; increased confidence in inspecting various components; an understanding of how to interpret drawings to avoid confusion and an appreciation of the conditions or inaccuracies that can affect measurement as a whole.

The course provided benefits in all areas of DPC Quality Control - increasing production efficiency, accuracy and, ultimately, ensuring customer satisfaction.

"The NPL Training undertaken recently by 8 personnel was very successful for DPC, as although all personnel on the course were skilled engineers, their knowledge and understanding of tolerances, inaccuracies and measuring techniques were greatly improved giving them increased confidence and subjectivity to take back to the shop floor," said Simon Dawson, Managing Director, Dawson Precision Components. "We plan now to roll out Level 1 NPL Training throughout the factory and also to progress key personnel to Level 2."

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6th BSSM International Conference on Advances in Experimental Mechanics

The British Society for Strain Measurement (BSSM), recently held their 2008 Conference and Exhibition of Experimental Mechanics at NPL.

The conference took place over three days in early September, attracting nearly 100 visitors from home and abroad, including delegates from Israel, France, Sweden and Mexico. As well as presenting their conference papers, and attending the exhibition, delegates were given the opportunity to tour NPL's extensive facilities showcasing some of the work in structural health monitoring, acoustics, surface topography, dimensional measurement and acoustic thermometry.

Professor Janice Barton, BSSM past chair said "BSSM were delighted to hold the conference at NPL. The facilities are excellent with a superb lecture theatre and AV equipment and the reception area was ideal for our EMex exhibition. I received lots of positive feedback from the delegates regarding the venue, in particular the arrangements for the guest wi-fi. BSSM are very grateful to NPL for providing the facilities for the conference. In particular we are grateful to Dr Jerry Lord for his input above and beyond the call of duty".

NPL are corporate members of the BSSM, and Jerry Lord has just been appointed vice-chairman for the next two years.

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Forthcoming Events:

Below are just a few of NPL's events, to see the full listings please visit: www.npl.co.uk/events

14th International Congress of Metrology

22 - 25 June 2009
Paris, France

Measurement as a strategic tool for improved production, faster cycles and lower costs. Nearly 1000 participants from fifty countries, with 180 presentations, 90 exhibitors, 4 technical visits and 6 industry round tables discussing: what's at stake for metrology in the health field; metrology and reduction of greenhouse gas emissions; metrology and industrial performance; industrial temperatures and new materials; accreditation, economic & strategic issues and wireless measurements in the industrial environment.

Contact: info@cfmetrologie.com
www.metrologie2009.com/index_en.php

UK Scanning Probe Microscopy 2009

24 - 25 June 2009
NPL, Teddington

The conference will cover a wide variety of applications from biological molecules, biomaterials, polymers, crystals, metal and catalyst surfaces, nanostructures, nanomanipulation, dimensional metrology, instrument and probe development, and more.

Contact: charles.clifford@npl.co.uk
www.npl.co.uk/ukspm2009

Lamdamap 2009 International Conference

29 June - 2 July 2009

Brunel University, London and NPL, Teddington
Brunel University and NPL are proud to jointly host the 9th International Conference and Exhibition on laser metrology, machine tool, CMM and robotic performance (LAMDAMAP).

Contact: Hannah Carter on 020 8943 6612 or e-mail hannah.carter@npl.co.uk
www.npl.co.uk/lamdamap2009

Metamaterials 2009

1 - 4 September 2009
Queen Mary University of London, UK

The 3rd International Congress on Advanced Electromagnetic Materials in Microwaves & Optics

Contact: hannah.carter@npl.co.uk
http://congress2009.metamorphose-vi.org/

Measurement Good Practice Guide No. 110, *Good practice guide to reduce copper dissolution in lead-free assembly***,** (Di Maio, D, Hunt, C P, Willis, B, 2008), ISSN: 1368-6550, is now available from **www.npl.co.uk/guides** or paper copies can be ordered from **http://publications.npl.co.uk/npl_web/request_form.html**

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NPL occupies a unique position as the UK's National Measurement Institute and sits at the intersection between scientific discovery and real world application. Its expertise and original research have underpinned quality of life, innovation and competitiveness for UK citizens and business for more than a century.

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