

# UK'S PROVISION OF PRIMARY HARDNESS STANDARDS

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*Abstract: As a result of a EUROMET agreement the NPL programme on hardness was discontinued in 1988. Representation from UK industry (equipment manufacturers and users of hardness measurement) through the British Measurement and Testing Association (BMTA) requested that a national centre of hardness measurement and calibration excellence should be re-established in the UK.*

*This paper describes the UK's re-establishment of a national system for traceable hardness measurement and the hardness scales supported. Details are presented on two hardness machines designed and built by Instron Ltd. The requirements for the measurement of both indentations and indenters are also discussed. Ancillary equipment has been purchased and modified where necessary for NPL's use.*

*Keywords: Hardness, Hardness calibration*

## 1 INTRODUCTION

The NPL hardness standards programme was discontinued in 1988 in favour of a EUROMET agreement under which IMGC of Italy took over the responsibility of providing primary hardness calibrations to UK users. Representation by the UK manufacturers of hardness equipment and users of hardness measurements made through the British Measurement and Testing Association (BMTA) requested that a national centre of excellence in hardness measurement be re-established in the UK in order to: (i) provide a local calibration service, (ii) provide a source of advice and consultancy to UK industry, and (iii) re-establish the UK's influence in the development of international hardness standards.

Hardness is an unusual physical property in that measurement is essentially arbitrary, and not susceptible to precise definitions in terms of fundamental units of length, mass and time. In practice, hardness is measured in terms of the size of an impression made on a specimen by an indenter of a specified shape when a specified force is applied for a specified time. Because of the arbitrary nature of hardness, standards are critical in securing uniformity of measurements. Such standards are realised by both indirect calibration of the hardness machine, using traceable hardness blocks, and direct calibration of the applied force and distance travel by the indenter whilst making an indentation.

## 2 THE NPL HARDNESS PROJECT

The original project proposal was made jointly by NPL and Instron Ltd, with the latter responsible for design and manufacture of the hardness machines, control system, and software.

Much discussion ensued over the design of the hardness machines and despite the metrological simplicity of deadweight machines, they lack flexibility. It was agreed that further advances in hardness metrology would best be made using servo-controlled screw drive machines; the major advantage being the ability to accurately reproduce a wide range of loading cycles.

There was also a requirement for equipment to measure: (i) the size of indentation, and (ii) the morphology of indenters. For both these requirements NPL used the experience of IMGC, together with associated commercial developments and existing equipment at NPL.

### 2.1 Hardness scales

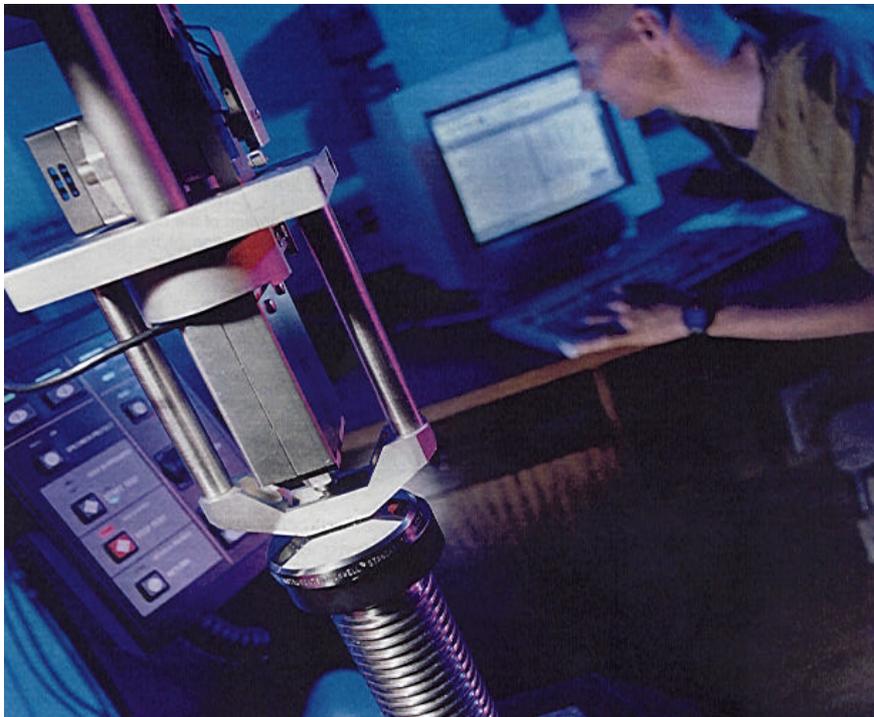
The national standard hardness machines have been designed to cover the hardness scales most commonly used in UK industry. These scales are based on those requested by BMTA and were agreed with the United Kingdom Accreditation Service (UKAS). In future projects NPL will extend the range, as these scales are seen as the minimum requirement for the UK. The supported hardness scales are as shown in Table 1.

**Table 1.** Hardness scales supported.

|                      | Scales       | Nominal Force (N) |
|----------------------|--------------|-------------------|
| Brinell              | HB10/3000    | 30 000            |
|                      | HB10/1000    | 10 000            |
|                      | HB5/750      | 7 500             |
|                      | HB2.5/187.5  | 1 900             |
| Rockwell             | HRB          | 100 to 900        |
|                      | HRC          | 100 to 1 500      |
| Superficial Rockwell | HR30N, HR30T | 100 and 300       |
| Vickers              | HV10         | 100               |
|                      | HV30         | 300               |

## 2.2 Hardness Machines

The need for high accuracy hardness machines to cover the above hardness scales meant that a minimum of two machines were needed to re-establish UK hardness standards and provide a broad calibration service. The machines are designed such that additional macro-hardness scales can be implemented.



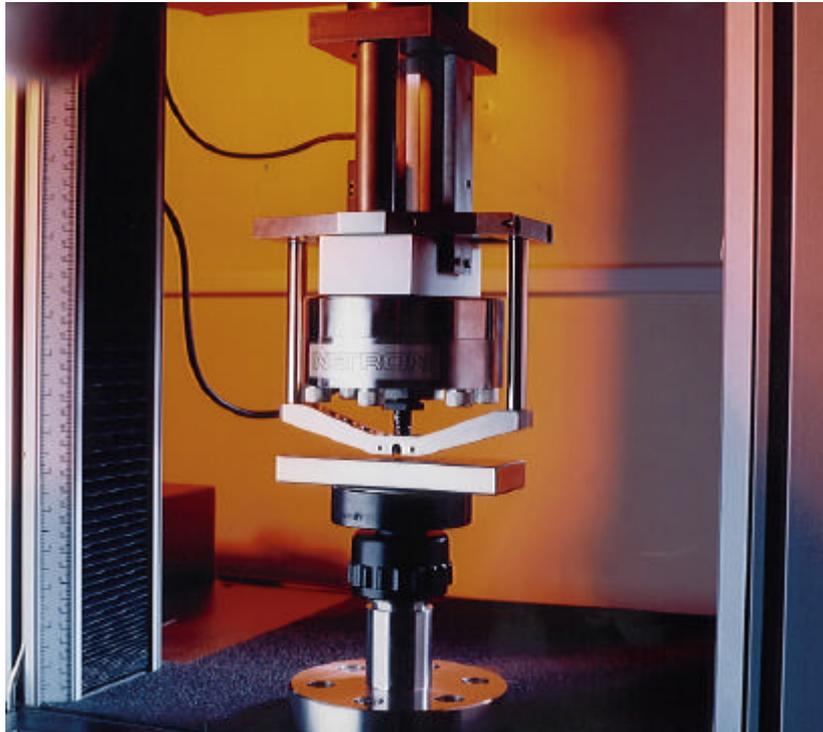
**Figure 1.** Machine 1, applies forces from 30 N to 1500 N.

The two machines were specified by NPL with the assistance of Instron Ltd. Instron designed the hardness machines using available frames and servo-controlled screw drives. Machine 1 applies forces from 30 N to 2000 N (Fig. 1) and Machine 2 applies forces from 1500 N to 30 kN.

To eliminate torque from the screw drive, the machines are designed with twin reaction columns. The applied force is measured by high accuracy load cells, traceable to NPL force standard machines. Indenter depth measurement is by Heidenhain sensors with a resolution 1 nm. The Heidenhain depth measurement sensor is calibrated using laser interferometry traceable to the UK realisation of the meter at NPL. Time control of the loading cycle and the measurement of indenter velocity will be calibrated against the UK time standard at NPL.

Machine 1 is based on the Instron RT2000 hardness machine, and is able to cover force and displacement demands of the Rockwell scales HRA to HRK and superficial Rockwell scales from HR15N to HR45T. In addition, the machine will be able to meet the force requirements of Vickers scales from HV5 to HV100 and the Brinell scales from HB2/4 to HB5/125.

Machine 2 (Figure 2) is based on the Instron 5567 tensile/compression testing machine, and is capable of supplying force requirements of the Brinell scales from HB2.5/187.5 to HB10/3000. Machine 2 also has depth measurement for macro-Rockwell scales and comparison with machine 1.



**Figure 2.** Machine 2, applies forces from 1500 N to 30 kN.

Both machines are interfaced to their own PC driven control system based upon Instron's Merlin and Wavemaker software products [1]. This software uses generalised waveforms for closed loop control. The servo design provides control of the applied force and indenter motion and avoids the risk of load overshoot present in some deadweight machines. Such control will provide demonstrable compliance with new hardness standards. It will make these hardness machines suitable for carrying out instrumented indentation hardness tests, i.e., universal hardness tests. Further, the flexibility of the control system software allows easy modification to the force application and provides a method for varying the hardness cycle. This facility enables hardness cycles of other national standard hardness machines to be reproduced, providing that the appropriate data files from such machines are made available.

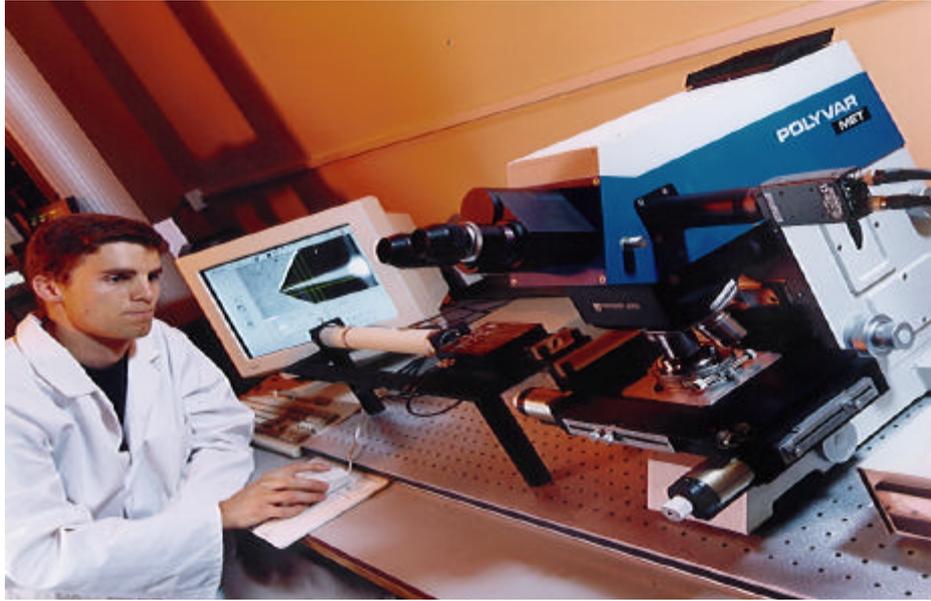
Both machines are at an advanced stage of commissioning and inter-comparisons with other national standard hardness machines are underway.

### 2.3 Indentation Measurement System

Previous experience at NPL indicated that the best way to measure hardness indentation width, albeit primarily in micro-hardness [2], was probably by the use of an optical microscope and a stage fitted with a laser interferometer. The microscope is required to have high precision objectives of sufficient numerical aperture to distinguish the indent against the bright surface of a hardness test block. The image display must be optimised for grey levels to ensure standardisation of contrast for imaging the "true" edge of an indent; this can only be established by comparison with other national standard laboratories and experience.

The indentation measurement system (figure 3) consists of a microscope with CCD camera to image the indents, a interferometer to measure the movement of the stage and image analysis software that controls the measurement process. The software system has been developed by Graftek Italia Srl for IMGc. This system minimises human manipulation of "cross-hairs" in identifying the diagonal vertexes of a Vickers indent or the diameter of a Brinell indent. The edge of the indents are recognised by comparison with templates for either Brinell or Vickers indents. The measurement is accomplished by positioning one vertex of the indentation in roughly the centre of the image and measuring the distance the stage has to move to position the opposite vertex in the centre. The final

value is the sum of the stage movement plus the distance of each vertex from the exact centre of the screen. The method corrects for any misalignment of Vickers indents with the horizontal axis.



**Figure 3.** Indentation measurement equipment.

The stage movement is measured using a Jamin interferometer and mirrors attached to the side of the microscope stage.

#### 2.4 Indenter Characterisation System

Figure 4 shows the indenter characterisation system, developed by LTF Gal-Indent for IMGC. The system contains: (i) an interferometer sine bar, for angle/geometry of Vickers indenters and cone/tilt angles of Rockwell indenters, and (ii) a rotary table for measuring the spherical tip of Rockwell indenters. Details of this indenter characterisation system, and its development are described elsewhere [3, 4] and are therefore only briefly discussed in this paper.



**Figure 3.** LTF Gal-Indent system.

The sine bar workstation is based on a Mirau interferometer mounted on a metallurgical microscope equipped with a x10 DI objective lens. To evaluate the angle of the faces of a Vickers indenter, an indenter is placed in the sine bar and tilted until a diffraction pattern is observed on one of its faces. The number of fringes is minimised to ensure that the face of the indenter is perpendicular to the lens.

When the face is perpendicular to the lens the movement of the sine bar is measured and used to calculate the angle of the indenter face relative to the shaft. The angle of the cone of a Rockwell indenter is evaluated using a similar technique. The flatness of each face can be determined from the number of fringes seen when the face is aligned perpendicular to the lens and the offset line determined from on screen measurement using a 100x lens.

The rotary table uses an LVDT to measure the radius of the tip of a Rockwell indenter. The table rotates around the tip of the indenter to measure any deviation of the radius of the tip from the ideal value of 200  $\mu\text{m}$ .

Both systems are connected to a computer system that performs automatic data acquisition.

### **3 PERFORMANCE OF HARDNESS MACHINES**

Both indirect and direct verifications of the two hardness machines have been carried out and their performance is discussed elsewhere [5]. Modifications have been made to the 1.5 kN hardness machine following the results of the verifications. A modification to improve the performance of the 1.5 kN machine was the implementation of a laser interferometer to measure the depth of indentations.

### **4 CONCLUSIONS**

Both hardness standard machines are in an advanced stage of commissioning and inter-comparisons with other national standard hardness machines are underway.

Indentation and indenter measurement systems have also been commissioned.

The establishment of a national calibration service is scheduled for Spring 2000.

### **ACKNOWLEDGEMENT**

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### **REFERENCES**

- [1] TestProfiler Option for Merlin II, Instron publication, 1997.
- [2] I.C. Leigh, The micro-indentation hardness test: The practical realisation of a standard. Ph.D. Thesis, University of Surrey, 1983.
- [3] F. Turotti, A. Ligori and G. Gori, LTF Spa contribution to the standardization of hardness measurements, HARDMEKO '98, Proceedings of International Symposium on Advances in Hardness Measurement, (Beijing, China 21-24 September 1998) p. 41-46.
- [4] G. Barbato and S. Desogus, Measurement of the spherical tip of Rockwell indenters, Journal of Testing and Evaluation, JTEVA, v. 16, No. 4, July 1988, p. 369-375.
- [5] G.C. Stanbury, F.A. Davis, The uncertainty evaluation of NPL's hardness facility. XVI IMEKO World Congress, Vienna, Austria, September 25-28, 2000.

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