Hardness Testing by UCI Method

BAQ

Automatisierung und Qualitätssicherung

Introduction

For decades already, the UCI method (Ultrasonic Contact Impedance, as defined in standards ASTM A1038 and DIN 50159), has achieved a good reputation as simple, reliable and quick procedure for hardness testing. In former times, it was merely used in special situations -instead of stationary testing by means of methods according to Rockwell, Brinell or Vickers- in the case of large and complex objects or locations difficult to access. Nowadays however, it is accepted as the first choice for many objects, e.g. for pipelines, weld seams, toothed wheels, or generally on metal surfaces.

Measuring Principle

From a certain point of view, the UCI method is similar to Vickers testing, but here optical analysis by microscope can be omitted, as the hardness value is determined directly during the penetration itself. This fact proves to be advantageous for automated testing, thus enhancing flexibility in practice and supporting also extremely fast production cycles.

Like in Vickers procedures, a defined test load (3 to 98 N) is applied on the sample to be inspected. For that purpose, a Vickers diamond with exactly specified geometry acc. DIN EN ISO 6507-2 is used, mounted on the end of a vibrating rod. Subjected to longitudinal vibrations created by piezoelectric crystals, this rod is initially vibrating at its natural resonance frequency of 66 kHz (ref. to fig. 1).

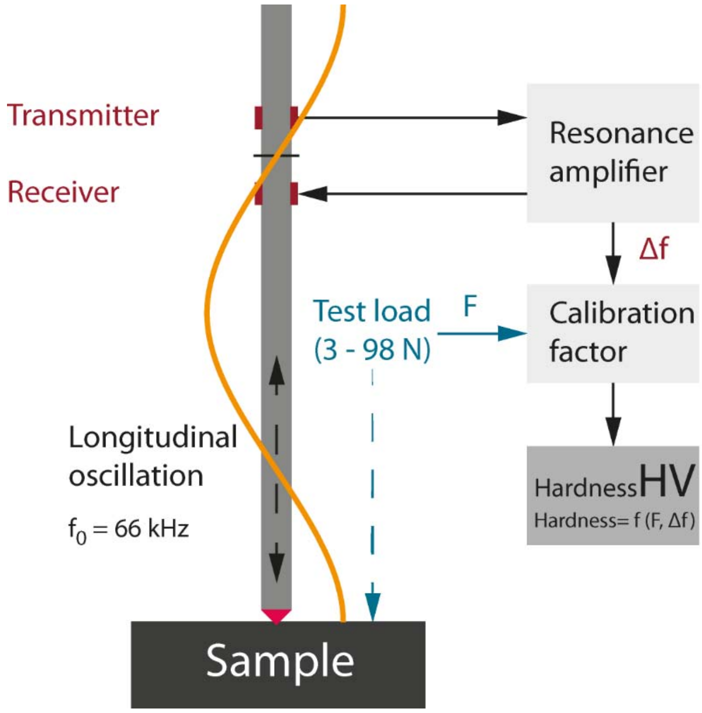


Fig. 1: Vibration of the UCI rod (transmitting and receiving piezo crystals shown on the left, resonance amplifier on the right, sample below)

While the vibrating rod together with the Vickers diamond progressively penetrates into the sample, the oscillation is damped, in parallel to the rising force respectively indentation depth. Due to this effect, the frequency of resonance changes. This change of frequency, in correlation with the increasing contact surface between diamond and sample (therefore the hardness) represents the actual parameter to be measured. This means simply that softer materials give rise to a larger contact area than hard items. General rule:

Hardness = f(F, Δf) with: F: Test load
Δf: Displacement of resonance frequency

The entire procedure is visualized in fig. 2. In the beginning, the system vibrates at its natural undamped frequency f_0 of 66 kHz. As the test load is continuously increasing, the simultaneously measured frequency shifts, as the contact surface is becoming larger. When the specified test load (in this case 49 N) is reached, the resulting difference to f_0 is calculated and transformed into a hardness value. Note that for models UCI alphaDUR II und alphaDUR mini, as well as for hardness scanner UT 200, the whole measurement takes only a few thousands of a second and leaves nearly no trace on the sample.

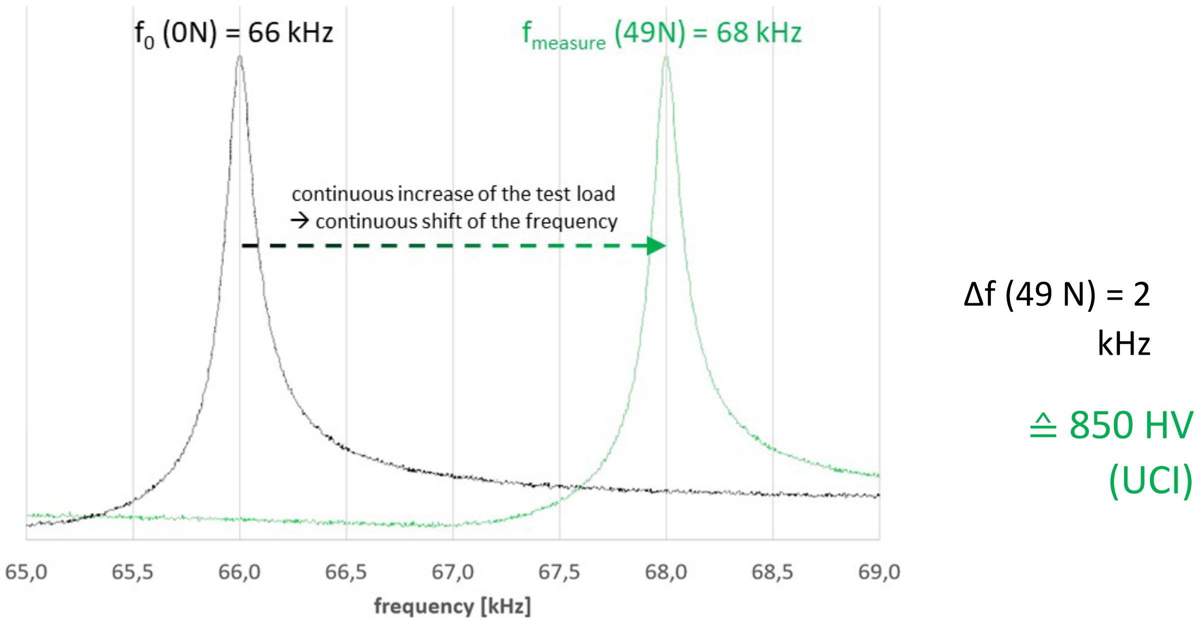


Fig. 2: Displacement of frequency with increasing test load during the UCI hardness test

It is important to know that the change of the frequency does not only depend on the hardness, but also on the modulus of elasticity. For this reason, the system must be calibrated correspondingly. This calibration takes place by means of hardness test blocks consisting of steel at different hardness. Hardness results are always calculated on the basis of these stored calibration values.

In defined material groups (e.g. steel between 200 and 210 GPa), the fluctuation of the modulus of elasticity is low and therefore can be neglected. In the case of a considerably differing modulus of elasticity however, first perform a calibration by means of a reference sample of the material in question. After completion of corresponding stationary hardness measurements, transmit the determined hardness value into the alphaDUR mini / alphaDUR II / UT200 by means of UCI measurements. This way the calibration curve itself is displaced, enabling precise measurements of the new material to be achieved.

Specific Test Configurations

As this testing method can be conveniently adapted to a great variety of applications, BAQ has developed individual solutions for numerous tasks, ranging from mobile devices with test probes to automated measurement equipment in production lines, and even fully automatic surface inspection in two dimensions.

Mobile Hardness Testing

A mobile station is composed of a test probe and a portable alphaDUR mini or alphaDUR II device so the procedure can be performed directly on the spot. Thanks to the shape of the probe, this is possible also in positions normally out of reach. Furthermore, the result does not depend on the direction. The probe has to be placed on the desired object; the load has to be applied manually – and the hardness value appears without delay.

Fig. 3: Mobile hardness test with model alphaDUR mini

The informative value of the method can be enhanced by recording sequences. All results including statistical analysis are displayed by the instrument and can be obtained as a printout, stored or transferred to a PC. To define a tolerance, specify upper and lower limits. Results outside this range are marked and additionally accompanied by an acoustic warning signal.

For both models (alphaDUR mini and alphaDUR II), conversion to another hardness scale is provided. This transformation takes place directly inside the instrument and is available acc.to DIN EN ISO 18265 - Feb.2014 and ASTM E140 - 12b (2019) in scales of Vickers, Brinell and Rockwell, or also converted to results of tensile strength.

For the practical test procedure, it is essential to place the probe onto the surface of the specimen in exactly vertical orientation, as otherwise the contact area would be reduced. Skewed orientation (acc. to DIN 50159 and ASTM A1038: > 5°) affects the contact area in an inadmissible way, displacing the frequency and falsifying the hardness result.

This problem is often encountered by unexperienced personnel. Besides precision measurement stands used in laboratory environment, BAQ therefore offers probe supports, useful particularly in mobile applications. Simply screw the positioning aid onto the probe from below (instead of the protective sleeve). These probe supports are available for different tasks, i.e. for flat or curved parts e.g. tubes. When using these auxiliary aids, the test load has to be applied manually as well.

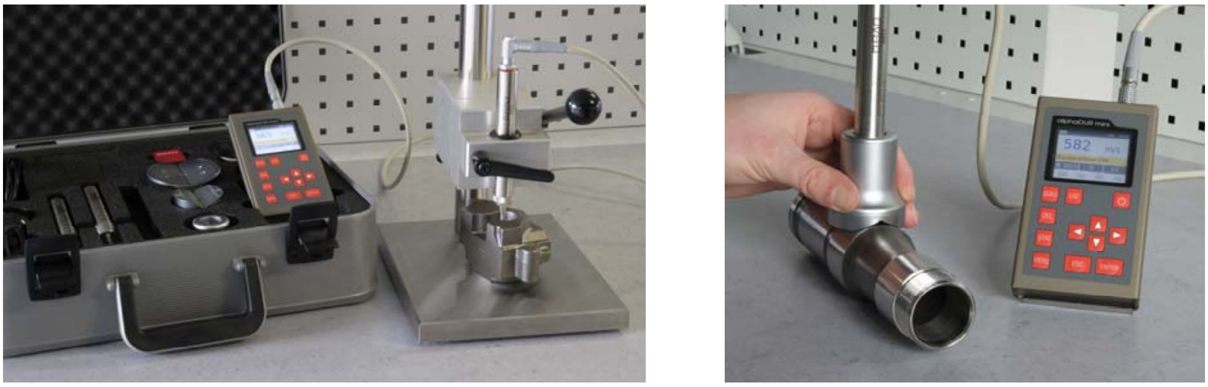


Fig. 4: Increased precision by measurement stands (on the left) and positioning aids (on the right)

Automated Hardness Testing in Production Lines

Fully automatic 100% testing in production lines can be established by means of the alphaDUR II SPS model. Thanks to the extremely fast procedure, cycle times of only a few seconds are not an obstacle.

The purpose of Pass / Fail testing consists in identification of bad parts. For this reason, tolerance limits may be stored in the memory of the alphaDUR II SPS, causing a message to be transferred to the SPC in case of need, so that the concerned part can be sorted out immediately. The message can also be accompanied by the exact hardness value.

Fig. 5: alphaDUR II SPS for measurements in a production line

Fully Automatic Surface Inspection

In addition to the test blocks described beforehand, BAQ has developed the hardness scanner model UT200, which is based on the UCI principle as well. Positioning takes place under program control, and the load is applied in a motorized process, so that a fully automatic measurement run for surface or line inspection can be configured. It is also possible to test several samples in one single sequence. The speed of the UCI method enables several thousand measuring points to be recorded within shortest delay, which opens completely new horizons for materials testing.

Summarizing the values in a colored diagram clearly makes visible the material properties at a glance, e.g. the microstructure in a weld seam or the transitions between base material and hardened zones.

Fig. 6: Hardness scanner UT200, specialized in surface inspections

Boundary Conditions / Requirements to be met

Like for every hardness testing method, the quality of the UCI measurement depends on several requirements, which must be known. A certain experience of the personnel is imperative, but also for the specimen itself some conditions must be fulfilled.

In order to ensure the operational capability of the alphaDUR mini oder alphaDUR II models for particular types of samples, preliminary examinations may be useful. This can be realized by means of rental devices or by test measurements of original samples inside our BAQ laboratory. Furthermore, our customer service is always ready for a demonstration of the test equipment on the spot. We have an international network of qualified partners, experienced in all technical questions concerning the configuration of a meaningful test design.

Sample Thickness

According to DIN 50159-1, a minimum thickness of 5 mm of the specimen must normally be ensured, as otherwise the original ultrasonic signal emitted by the vibrating rod, partially transferred into the piece could interfere with reflections from opposite boundary surfaces. This fact could give rise to misinterpretation of the results.

The superposition of the ultrasonic waves can however be suppressed by applying a thin oil film on the interface between the sample and an additional massive body; this method is called coupling. This way, instead of being reflected, the wave propagates into the adjacent body, and no interference takes place. The base plate of the precision measuring stand may be used for that purpose. Another method consists in embedding the sample, which proves to be practical in the case of surface measurements by means of the UT200 scanner. Both methods enable tests to be performed also for smaller samples.

Surface Roughness

The validity of all hardness measurement methods is restricted to a defined maximum average roughness Ra. For the UCI method, the limits are specified in DIN 50159-1 respectively ASTM A1038, as follows:

Test Force	Surface Roughness Ra_{max} in µm	
	Acc. to DIN 50159	Acc. to ASTM A 1038
98 N	1	15
50 N	0.8	10
10 N	0.5	5
3 N	-	2.5

Note: In contrast to the Vickers method measuring the diagonal lines of the impression (with corner points sometimes hard to be determined in the case of rough surfaces), the UCI method makes use of the entire contact area to calculate the hardness result. This generates an averaging effect significantly lowering the scattering of the results.

In order to ensure compatibility with the requirements, the surface may conveniently be prepared. Partial grinding of the measuring point is sufficient, use the following table as a reference:

Grain sizes acc. to FEPA-Standard	120	180	240
Ra	ca. 1.2 µm	ca. 1.0 µm	ca. 0.6 µm

Layer Thickness

The hardness of layers (coatings) on surfaces can be checked by the UCI method as well. In order to avoid influences originating from the base material, the penetration depth of the Vickers diamond has to be limited to 1/10 of the layer thickness. Use the following diagram as a reference:

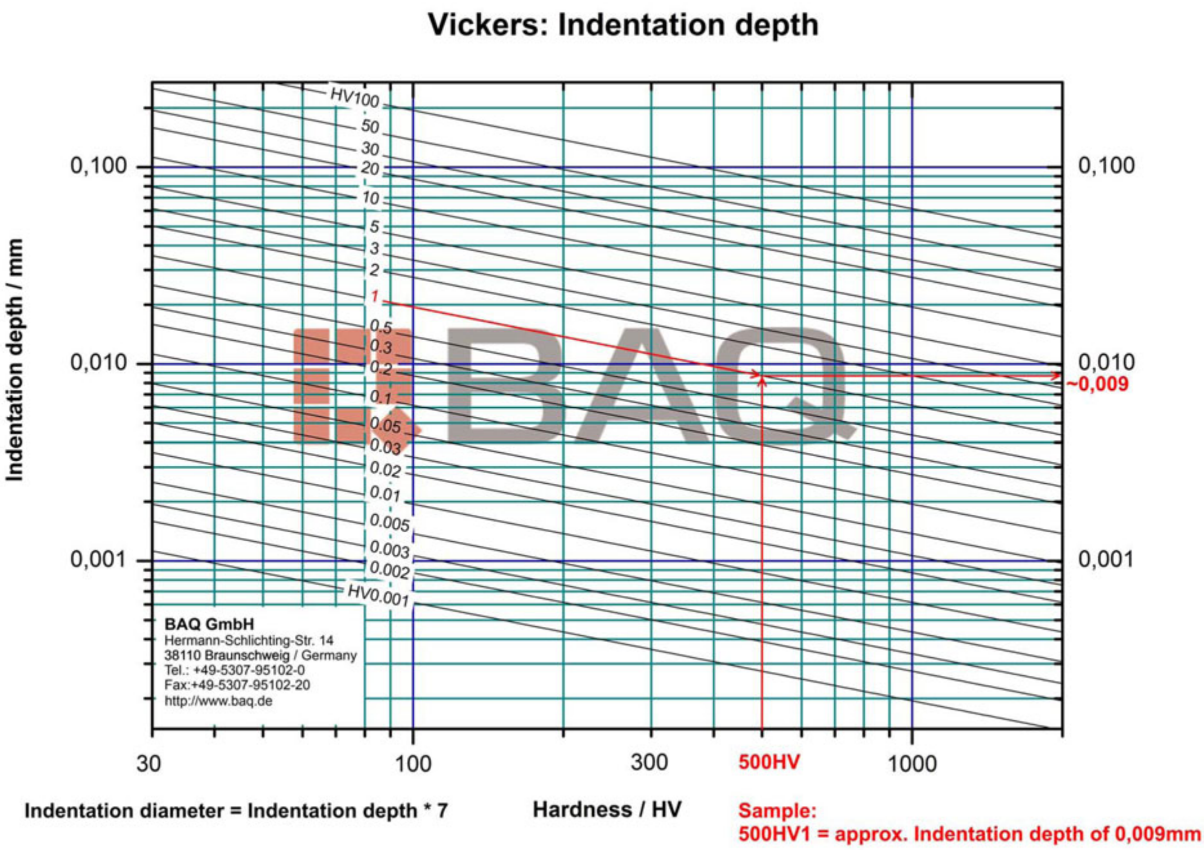


Fig. 7: Diagram of Penetration Depth (example: depth of 0.009 mm), diagonal of impression = depth * 7

Correct Selection of Test Load

UCI test probes are available with test loads between 3 N (HV0.3) and 98 N (HV10). All probes are admitted for all hardness ranges; only their handling is different. The correct selection of the test load depends on the surface roughness of the sample. As a rule, keep in mind:

„The proper test load of the probe increases with the surface roughness!“

The following exemplary applications are mentioned in DIN 50159-1:

Test Load	Typical Applications
98 N	Small forgings, weld seam inspection, verification of heat affected zone
49 N	Induction or case-hardened machine parts, e.g. camshafts, turbines, weld seams, verification of heat affected zone
10 N	Ion nitrated stamping tools and matrices, forms, presses
3 N	Layers, e.g. copper and chromium layers on steel cylinders (t ≥ 0.040 mm), rotogravure cylinders, coatings, hardened coatings (t ≥ 0,020 mm)

Advantages of the UCI Method

▪ Mobile inspection	Measurement directly at the component concerned
▪ Independence from direction	Measurement in any orientation
▪ Quick procedure	Optical analysis of the indentation unnecessary
▪ Improved precision and reproducibility	The entire contact surface is used for calculation, not only the diagonal line. → Therefore enhanced reliability in the case of asymmetrical impressions
▪ Nearly non-destructive	Impressions hard to detect (refer to fig. 8)
▪ Simple automation	Inline test (i.e. integrated into the production line)
▪ Compact design	Ideal for positions difficult to reach, complex part geometries and in narrow spaces

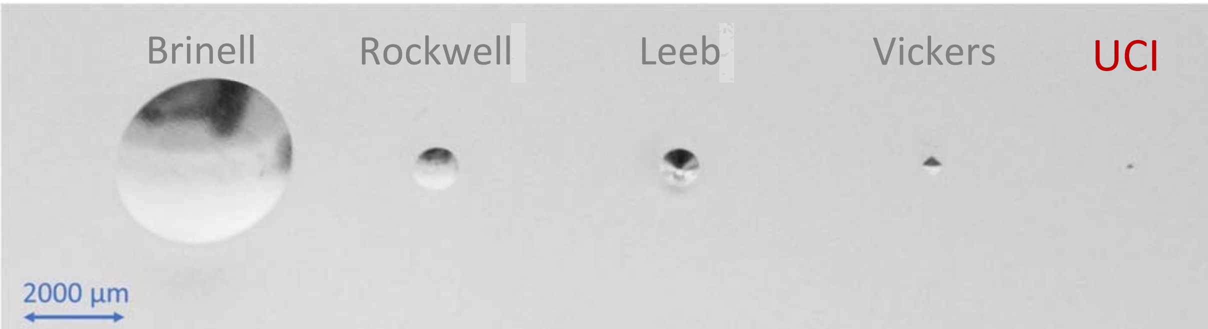
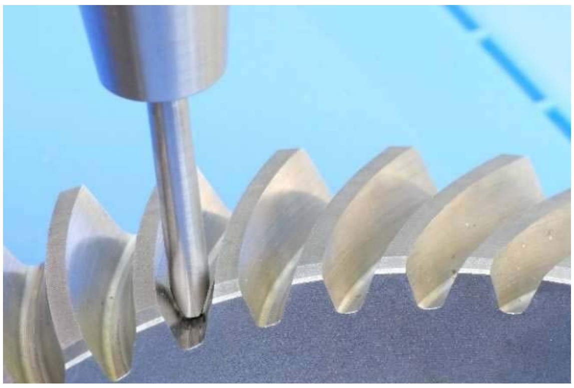


Fig. 8: Impression of different hardness testing methods
Brinell HBW 10/3000; Rockwell HRC; Leeb HLD; Vickers HV10; UCI HV1

Applications

- Quality control
- Incoming inspection
- Supervision of production
- Pass / Fail testing
- Identification check
- Weld seam inspection
- Effective hardening depth / profile of hardening depth
- Hardened and unhardened pieces
- Coatings
- Complex sample geometries
- Surface scans and line measurements
- Inspection of internal components



Standards

- DIN 50159-1,2
- ASTM A 1038
- ASTM E 140-13 (conversions)
- EN ISO 18265 (conversions)