FAQ's – Hardness Testing

# FAQ's – Hardness Testing

FAQ 1: How do Rebound testers such as the DynaMIC and DynaPOCKET work?

The rebound method indirectly measures the loss of energy of a so-called Impact Body. A spring projects it towards the test piece and its spherical indenter strikes the object's surface at a defined speed. The indentation created absorbs a portion of the energy thereby reducing its original speed. The softer the material the larger the indentation and the higher the loss of energy.

The velocities before and after the impact are each measured in a non-contact mode. This is accomplished by a small permanent magnet within the impact body (see figure) that induces a voltage during its passage through a coil. The voltage created is proportional to the speed as shown in the figure below.
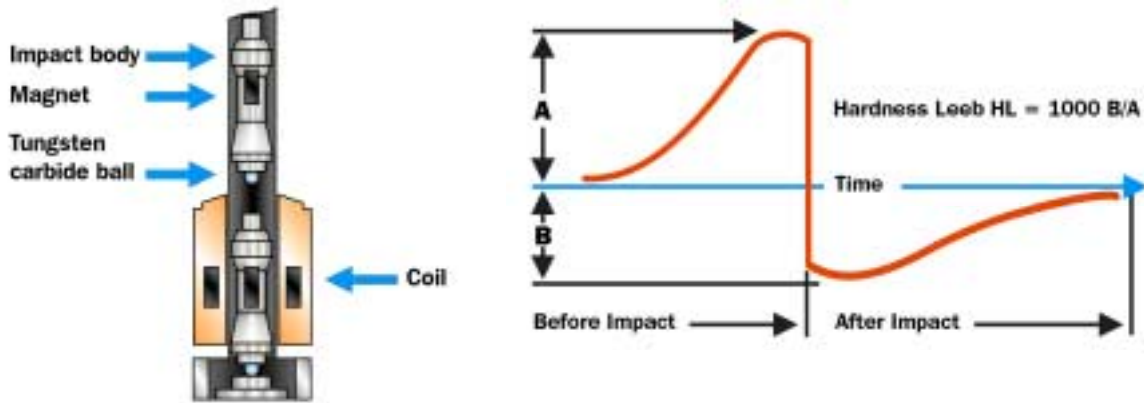
Cross-cut of a typical impact device

Voltage signal generated by the impact body travelling through the coil. The signal is shown before and after the impact.

The inventor of this method, D. Leeb, defined his own hardness value, the Leeb hardness value. The Leeb hardness value, HL, is calculated from the ratio of the impact and rebound speed according to: **HL = 1000 B/A** with A, B = speed before / after the impact

Who uses the Leeb value? The fact is that although the HL is the actual physical measurement value behind this method rarely does a user indicate the Leeb value in his specifications or test reports. Normally he reports a converted hardness value (HV, HB, HS, HRC, HRB, N/mm^2). Therefore conversion tables for various material groups are stored within the instrument. The graphic below illustrates such a conversion table.
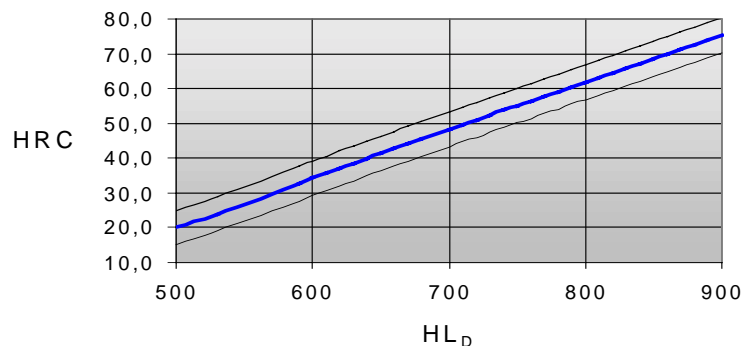
Conversion of Hardness Leeb, HL, into HRC as a typical example for conversion tables stored in rebound hardness testers. These curves are experimentally generated by material samples of different hardness measured by rebound and Rockwell test.

FAQ 2: How does the MIC 10 use ultrasonics to measure hardness?

Conventional Vickers or Brinell hardness testing requires optical evaluation of the area of an indentation produced by its indentor under a specified load. Testing using the UCI (Ultrasonic Contact Impedance) method the diagonals of the test indentation, which have to be known in order to determine the Vickers Hardness value, are not evaluated optically as usual, but the indentation area is electronically detected by measuring the shift of an ultrasonic frequency.

A UCI probe consists of a Vickers diamond attached to the end of a metal rod. This rod is excited into a longitudinal oscillation of approximately 70 kHz by Piezoelectric transducers. Imagine the rod as a large spiral spring held at one end and free to oscillate at the resonant frequency at the other end. Attached to the free end is a contact plate, the Vickers diamond. Now picture the surface of the material to be comprised of a system of smaller spiral springs positioned vertically to the surface with the quantity of these springs representing the elastic properties of the material (Refer to FAQ 11 for more information regarding how to properly calibrate the instrument for a materials elastic modulus).

The diamond's penetration depth into the material is determined by the material's hardness with a very hard material having a shallow indentation allowing only a few of these "atomic springs" to contact the diamond resulting in a slight frequency shift. On the other hand if a softer part is tested, the diamond penetration is deeper and the frequency shift is more significantly as additional "springs" are touched. This is the secret of UCI hardness testing: the frequency shift is proportional to the size of the test indentation produced by the Vickers diamond.
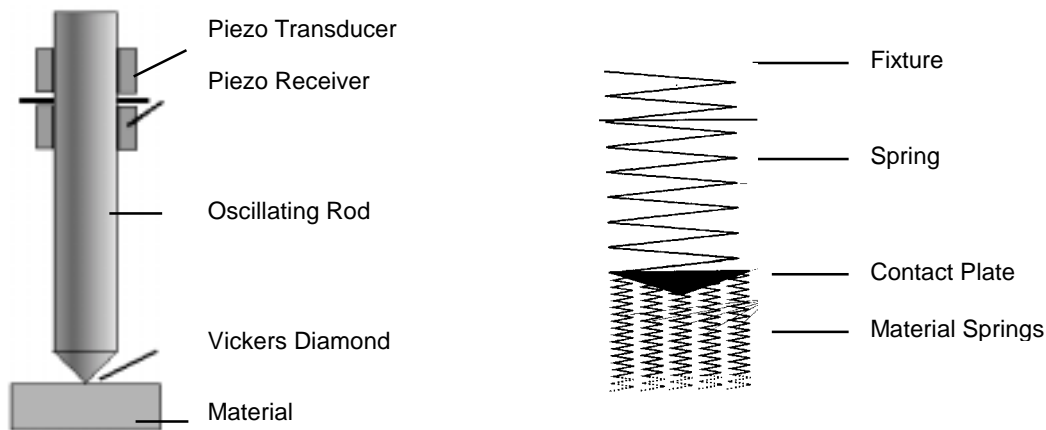
Schematic description of the UCI probe

UCI principle in an imaginary experiment: an oscillating spring in contact with material. The large spring represents the oscillating rod, the contact plate represents the diamond, the smaller springs represent the material and its elastic constants.

The equation below describes this basic relation in comparison to the definition of the Vickers hardness value.

$$\Delta f \approx E_{elast} \cdot \sqrt{A} \qquad\qquad HV = \frac{F}{A}$$

The graphic below illustrates the relationship of frequency shift to hardness.
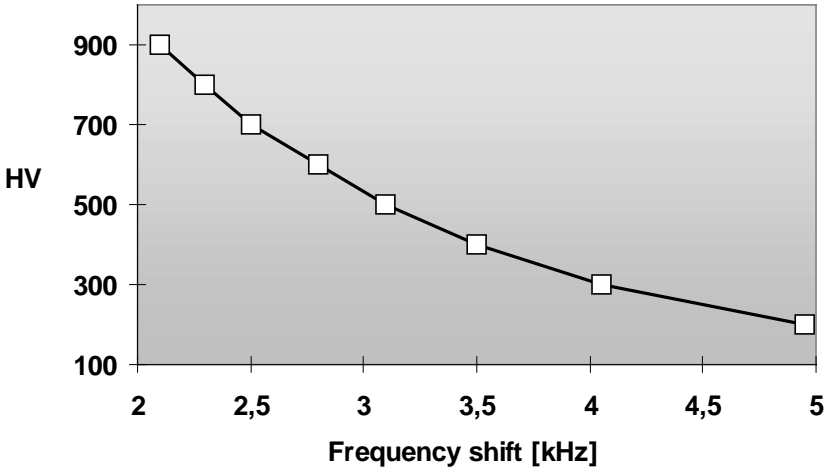
Vickers Hardness value versus frequency shift of the oscillating rod.

FAQ 3: What is the proper technique for carrying out a hardness measurement?

DynaMIC Series Including the DynaPOCKET

Pressing the Loading Tube of the impact device of the DynaPOCKET and DynaMIC grasps and suspends the impact body. Upon pressing the Release Button a spring propels it towards the part and hardness value is updated.

Aligning the impact device within 3° of being perpendicular to the surface is required. The standard support rings provided with each Dyna D and Dyna E can be used to test convex or concave radii greater than 30 mm (1.2 in.). The larger diameter of the Dyna G standard support ring requires the radius to be greater than 50 mm (2.0 in.).

Support rings are offered as accessories that can be used with the Dyna D and Dyna E impact devices. They are available to cover the range of 10-30 mm (0.4 to 1.2 in.) for testing the ID's or OD's of cylindrical and spherical shaped parts (see Dyna 41 and Dyna 42). Custom support rings are also available on request.

MIC 10 Series

The recommended technique for using a handheld probe is to use one hand to steady the probe at the bottom while the other hand applies the load in a slow and controlled manner. Force is continuously applied until the end of the probe sleeve contacts the material at which time the instrument displays the updated hardness value.

> Caution: To prevent damage to the diamond care must be taken not to twist the probe while the diamond is in contact with the test material.

To carry out a reading, the probe must be aligned perpendicular to within 5° of part's surface. Of course, the more precise the alignment the more consistent the results. To aid in alignment the protection sleeve can be removed and replaced with various probe shoes. For example a probe shoe with a V groove base is handy when testing cylindrical parts having a radius of 3 - 75mm (.12 - 3.0 in.) And a flat probe shoe, although designed primarily to test flat surfaces, also can be used in testing radii greater than 75 mm (3.0 in.).

FAQ 4: What model of your portable hardness testers will best solve my application?

Several factors enter in the decision as to what method and portable instrument package is best suited for a particular application.

As with conventional hardness testers the size of the indentation produced by the portable equipment is extremely important in determining its suitability for a hardness application. To obtain accurate and repeatable readings the indentation must cover several grains of the materials microstructure; must be proportionally larger than the surface roughness; and if testing coatings or surface hardened components their thickness must be at least 10 times larger than the indentation depth so as not to be affected by the softer substrate material.

The UCI method is recommended for testing fine grained material having any shape and size. It is especially used where material properties are to be processed with narrow tolerances, e.g. for determination of strain hardening on drop forged parts.

Rebound hardness testing is carried out on large, coarse grained materials, forged parts and all types of cast materials because the spherical tip of the impact device produces a rather larger indent than the Vickers diamond and therefore processes the characteristics of the casting structure better.

With the small indent of the Microdur UCI probes, determination of the hardness can be made on welded parts in the critical area of the weld, the heat affected zone (HAZ).

The Leeb and UCI methods can be influence by the mass and thickness of the part to be tested. Therefore both of these factors must be considered in determining the best method (refer to FAQ 5 for additional information).

A number of probes and impact devices having different test loads provide a large range of applications.

Application	UCI testing	Rebound testing
Solid parts	**+**	**++**
Coarse grain materials	**-**	**++**
Steel and aluminium cast alloys	**o**	**++**
HAZ with welds	**++**	**-**
Tubes: wall thickness > 20 mm	**++**	**++**
Tubes: wall thickness < 20 mm	**++**	**-**
Inhomogeneous surfaces	**-**	**+**
Thin layers	**++**	**-**
Difficult to access positions	**++**	**+**

(++ especially suited / + well suited / o suited sometimes / - not recommended)

Applications for UCI and rebound hardness testing.

FAQ 5: How can my parts mass and thickness affect the results and what are the minimum requirements?

The requirements for the part's thickness and mass are more demanding for the Rebound (Leeb) method than they are for the UCI method. Each method is influenced differently but a common solution is offered.

The DynaMIC / DynaPOCKET create a high force of about 900 N at the time of impact. Thin or lightweight materials will flex under this large impact, altering the rebound of the impact body from the surface typically causing the display of lower than actual hardness values.

Although the force of the UCI is considerably less (98N for the MIC-2010 probe) the problem with this method is that thin or lightweight components can go into self-oscillation. What occurs with the UCI method is an incorrect frequency shift to be measured causing erroneous and erratic values.

A possible solution for either method is a machined support that precisely matches the contour of part's back surface to reinforce and make it rigid. Extremely thin materials may also require the use of a light grease or paste to couple the part to the support.

The table below is provided as a guideline for determining mass and support requirements.

	Dyna D & E	DynaG	UCI Probes
No support required	> 5 Kg > 11 lbs.	> 15 Kg 33 lbs.	0.3 Kg 0.7 lbs.
Requires Support	2 to 5 Kg 4.4 to 11 lbs.	5 to 15 Kg 11 to 33 lbs.	0.1 to 0.3 Kg 0.2 to 0.7 lbs.
Requires Support & coupling paste	.05 to 2 Kg 0.1 to 4.4lbs.	.5 to 5 Kg 1.1 to 11 lbs.	0.01 to 0.1 Kg 0.02 to 0.22 lbs.

In addition to the test object's minimum mass, the wall thickness also plays an important part in selection of the test method. It can influence the hardness value even when the test object is solid and weighs a few tons. Wall thickness of tubes, pipelines or valves is critical for portable hardness testing. As an example, a thin wall will react like the skin of a drum when an impact body strikes it.

The following table is offered to provide guidelines for wall thickness however certain part geometry could stiffen the test piece allowing a thinner wall.

Hardness testing method	Wall thickness in mm	Wall thickness in inches
Rebound	20 mm	0.79
UCI	2-3 mm	0.08 – 0.12

The graphic below effectively illustrates the deviation of a Vickers test compared to that of the DynaD for varying wall thickness. Note that above 20mm there is good correlation between the different test methods indicating that the rebound tester provides a true value.
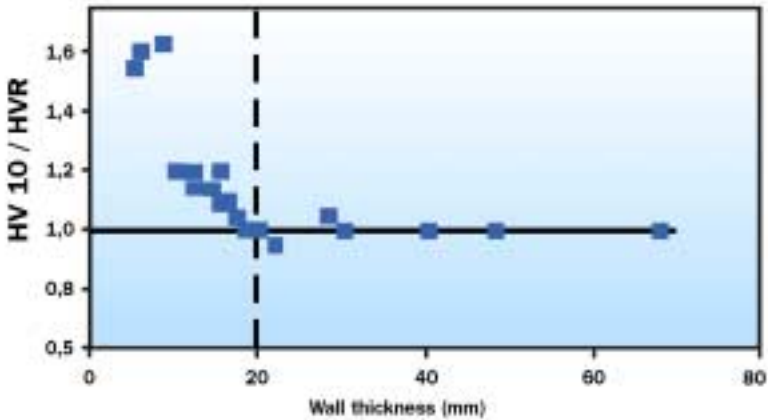
FAQ 6: What surface finish is needed and how can I properly prepare it?

All hardness test methods require smooth surfaces free of rust, paint, oil or protective coatings. The indentation depth must be large in comparison to the surface roughness.
Surface preparation can be performed using a battery driven, high speed (>12,000 rpm) handheld grinder. However, care must be taken not to alter the surface hardness by overheating or cold working.

DynaMIC Series Including the DynaPOCKET.
Coarse surfaces will tend to lower the measured value and cause a greater variation within a set of measurements. The graphic below illustrates the affects of variation in the Vickers values as a result to varying degrees of surface roughness that can be expected when using a DynaMIC with DynaD impact device or a DynaPOCKET.
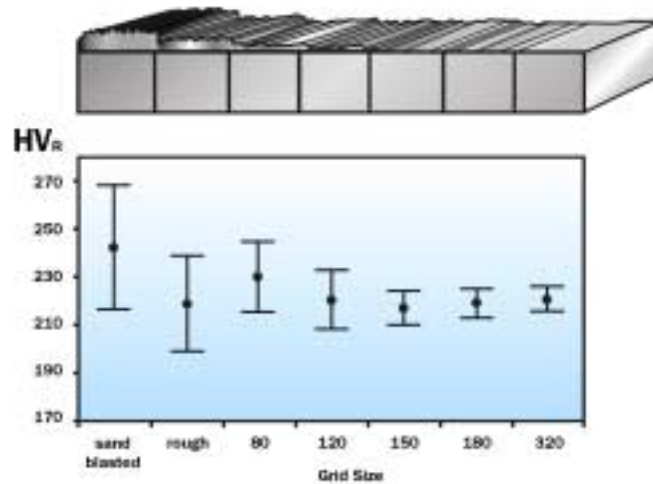
MIC 10 Series
Size of the indentations produced can vary greatly due to the extensive range in hardness possible with the MIC 10 and the available probe loads ranging from 0.3 to 10.0 kgf.   The MIC 10 provides very fast testing allowing the operator to quickly take a set of 5-10 readings. Experience has shown that the average of the set can be repeated if the surface has been sufficiently prepared.

FAQ 7: **How do I select the best MIC 10 probe for my application?**

The UCI method is best suited for testing homogeneous materials due to the small size of the indentations created. Five different loads (0.3, 0.8, 1.0, 5.0 and 10 kgf) are employed by the various models of UCI probes. The table below is offered as a general guide to selecting the appropriate probe for a variety of applications.

Load	Available Models	Advantage or Benefit	Typical Applications
98 N 10 kgf	MIC-2010 Standard Length Handheld Style	Largest indentation requiring only minimal surface preparation	Small forgings & HAZ weld testing
50 N 5 kgf	MIC-205 Standard Length Handheld Style	Solves most general applications	Induction or carburized machined parts, e.g. camshafts, turbines, HAZ weld testing
	MIC-205L Extended Length Handheld Style	30mm (1.2 in.) extended length designed for clearing obstacles.	Measurement in grooves & gears
	MIC-205S Short Probe Handheld Style	Reduced length to 90 mm (3.5 in.) electronics in separate housing for minimum height.	ID testing of pipes or tubes
10 N 1 kgf	MIC-201 Standard Length Handheld Style	Load is easy to apply; provides control to test on a sharp radius	Ion-nitrided stamping dies and molds, forms, presses, thin walled parts
	MIC-201L Extended Length Handheld Style	30mm (1.2 in.) extended length designed for clearing obstacles.	Bearing raceways & gears
	MIC-201S Short Probe Handheld Style	Reduced length to 90 mm (3.5 in.) electronics in separate housing for minimum height.	ID testing of pipes or tubes
8 N 0.8 kgf	MIC-211 Motor Probe Style	Use with urethane fixtures for complex shapes	Finished precision parts e.g. gears, & bearing raceways
3 N 0.3 kgf	MIC-2103 Motor Probe Style	Shallowest indentation	Layers, e.g. copper or chromium layers on steel cylinders (≥ 40 μm), Copper Rotogravure cylinders, Coatings, Hardened layers (≥ 20 μm)

UCI (MIC 10) probe models, their benefits and typical applications.

FAQ 8: How do I select the right DynaMIC impact device for my application?

Our series of rebound hardness testers includes the DynaMIC and DynaMIC DL instruments with interchangeable DynaD, DynaE and DynaG impact devices. The DynaPOCKET is an integrated model with an equivalent DynaD device built into the electronics.

Although a variety of impact devices are offered, the DynaD with a 3 mm tungsten carbide tip solves the majority of common applications. The Dyna E is similar mechanically to the DynaD but uses a diamond to provide a long service life for testing very hard parts (650 HV / 56 HRC or higher).
The DynaG impact body is much larger in size compared to the other two devices, which is necessary because it creates impact energy nine times greater and has a larger indentor. Typical applications for each device are listed in the following table:

Model	Indenter	Force (N mm)	Typical Applications
DynaD DynaPOCKET	3 mm Tungsten Carbide Ball	12	General purpose testing of homogeneous material
DynaE	3 mm Spherical Diamond	12	>50 HRC, e.g. forged and hardened steel mill rolls
DynaG	5 mm Tungsten Carbide Ball	90	<650 HB, e.g. Large castings and forgings, lower surface requirements

DynaPOCKET and DynaMIC Series Impact Devices, their benefits and typical applications

FAQ 9: Does gravity affect the results of the instrument?

NO. All of our portable equipment is unaffected by gravitational affects allowing complete and uninterrupted testing around the circumference of a cylinder.

DynaMIC Series Including the DynaPOCKET

All Leeb instruments currently on the market with the exception of the DynaMIC and DynaPOCKET are affected by gravity. The first instruments required the operator to use a lookup table and add a correction factor to the displayed value based on the impact devices orientation. Competitive instrument now on the market require the operator to input the test direction prior to carrying out a measurement so that the correction factor is added automatically to the displayed value.

However, what sets the DynaMIC and DynaPOCKET above all other Leeb instruments is our patented Autobalancing feature. Special signal processing not only calculates the hardness value using the ratio of the voltages required by the LEEB principle but also analyzes their phases to automatically compensate for changes in orientation. Eliminating the additional step to input direction improves productivity and assures the accuracy of the results. Due to the patented signal processing there is no need for any manual correction for the impact direction.

MIC 10 Series

The principle of the UCI method employed by the MIC 10 has always been unaffected by gravitational affects.

FAQ 10: Does your portable hardness test equipment meet ASTM standards?

DynaMIC Series Including DynaPOCKET

The DynaMIC and DynaPOCKET conform to ASTM Standard A956-00 entitled: *Standard Test Method for Leeb Hardness Testing Of Steel Products*.

MIC 10 Series

At this time the UCI principle of the MIC 10 is not covered under any ASTM standard.

FAQ 11: When is it necessary to calibrate the instrument and how is this accomplished?

Elastic modulus (Young's Modulus) is determined by the bonding forces of a material's atoms. It's a measure of a material's ability to return to it original condition after a load is applied and then removed. Elastic modulus is an important factor when converting values of different hardness tests methods and its influence must be taken into consideration to properly calibrate our portable hardness testers.

DynaMIC Series Including the DynaPOCKET

To calibrate the DynaPOCKET, the operator selects from one of nine material groups from the table below. Each material group represents materials having a similar elastic modulus and for most applications the results obtained are sufficiently accurate. However, material groups were generated using a limited number of alloys and therefore should be considered as a rough calibration.

The DynaMIC also provides the operator the selection from the same material groups. But for more demanding applications were tight tolerances are required it is possible to use the calibration feature to allow for a specific material. All that is required is a sample of the material which has been tested with the method specified, e.g. Brinell, Rockwell C, Rockwell B, etc. To perform the calibration, several readings are taken on the sample and the DynaMIC's displayed average value is adjusted to the actual "real" hardness. This establishes a calibration offset reference value for that specific material that can be used to recalibrate the instrument at a later time.

Material Group	HV	HB	HRB	HRC	HS	N/mm^2
1 Steel – Plain, Low Alloy or Cast		D, E, G	D, E, G	D, E, G	D, E, G	D, E, G
2 Tool Steel	D, E			D, E		
3 Stainless Steel	D	D	D	D		
4 Gray Cast Iron		D, G				
5 Nodular Cast Iron		D, G				
6 Cast Aluminium		D	D			
7 Brass		D	D			
8 Bronze		D				
9 Copper		D				

Material groups and available DynaMIC conversions
Letter indicates the impact device model (D also indicates the DynaPOCKET)

MIC 10 Series

UCI probes compatible with the MIC 10 series are calibrated on steel test blocks having an elastic modulus of 210,000 MPA (30 · 10^6 PSI). Because non-alloyed or low alloyed steels have a similar elastic modulus, accurate results are obtained with the standard calibration. In many cases, the difference in elastic modulus of medium and high alloy steels is so insignificant that the error created falls within the allowable tolerances of the part.

However, the elastic modulus for non ferrous materials require special calibrations. All that is required is a sample of the material which has been tested with the method specified, e.g. Brinell, Rockwell C, Rockwell B, etc. To perform the calibration, several readings are taken on the sample and the MIC 10 displayed average value is adjusted to the actual "real" hardness. This establishes a calibration offset reference value for that specific material that can be used to recalibrate the instrument at a later time.

Calibration offset values are referenced from a 0000 value for steel. Note that they can be either a positive or negative value. The following table contains a listing of approximate calibration values that can be referenced for some common materials.

Material	Calibration Offset Value
Aluminium	-8800
Chromium	+0250
Copper	-5800
Cast iron	-4800
Titanium	-6500
300 Series Stainless	-1500
400 Series Stainless	-0900

Approximate UCI Calibration Offset Values

FAQ 12: What is the accuracy I can expect and how is the equipment's performance verified?

Assuming that your parts have adequate thickness and mass for the chosen technique other factors relating to a specific application (e.g. shape, surface condition, the homogeneous nature of the material, etc.) can affect the overall accuracy you can expect to obtain.

The performance of any hardness tester can be assessed indirectly using standardised hardness reference blocks and by employing statistical methods.

DynaMIC Series Including the DynaPOCKET

The acceptable performance is based on 5 measurements on a certified Leeb test block having a nominal value of approximately 765 HL. The average of the 5 measurements should be within ±5 HL of the test blocks certified value.

A higher than acceptable average test block value indicates:
- The tungsten carbide ball is flattened and the impact body requires replacement.
- The area of the test block is completed use and should be replaced.

A lower than acceptable average test using block value indicates:
- A dirty impact device guide tube; clean with the supplied brush.
- The tungsten carbide ball is cracked and the impact body requires replacement.
- The support ring has a worn rubber pad and requires replacement.

MIC 10 Series

The specification for the MIC 10 is stated using certified Vickers test blocks. The average of 5 readings should be within ±3.6% of its certified value when using a ridged support such as the MIC-222 test stand. Testing freehand a minimum of 10 readings should be averaged and the tolerance is ±5%.

As a reference for comparison the ±3.6% HV range achievable with the MIC 10 Series converts to the Rockwell C scale as listed in the table below. Also to compare it to benchtop Rockwell testers the required repeatability for these hardness levels as defined by ASTM E18 is also listed.

	MIC 10 with Fixturing (3.6% of 5 readings)	MIC 10 Freehand (5.0% of 10 readings)	Rockwell Tester per ASTM E18
64 HRC	± 1.0 HRC	± 1.5 HRC	± 0.5 HRC
45 HRC	± 1.5 HRC	± 2.0 HRC	± 1.0 HRC
25 HRC	± 1.5 HRC	± 2.0 HRC	± 1.0 HRC

FAQ 13: **How thin a coating or surface treatment can I measure using the MIC 10?**

The UCI method is suitable for testing thin nitrided or carburized surface hardened layers or coatings such as chrome. To ensure that the reading is unaffected by the substrate material, the penetration depth of the Vickers diamond has to be considered. As a rule, the thickness of the layer should be a minimum of ten times the indentation depth. But nevertheless, the total thickness of the test piece should be at least 2-3 mm otherwise the sample has to be coupled to a support plate.

The minimum wall thickness of a layer / coating for hardness testing with the UCI (Vickers)

$$d = 0.062 \cdot \sqrt{\frac{\text{Test load [N]}}{\text{Hardness [HV]}}} \ \ [\text{mm}]$$

hardness tester depends on the probe load and the (estimated) hardness of the test material. The depth of penetration (d) can be calculated using the following equation:

And the minimum thickness (s) as mentioned above should be at least 10 times the penetration depth (d). **s > 10d**

The table below lists the depth of penetration using the above equation and minimum thickness based on the times ten rule for various hardness levels when using the MIC-2103 (3N or 0.3kgf load) and the MIC-211 (8.6 N or 0.8 kgf load) motorized probes. Keep in mind that the shallow indentations produced by these light loads require a very stringent surface finish.

Probe	Hardness	Penetration depth	Min. Thickness
	[HV]	µm	µm
MIC-2103 (3 N)	200	7,6	76
	400	5,4	54
	600	4,4	44
	800	3,8	38
	1000	3,4	34
MIC-211 (8.6 N)	200	12,9	129
	400	9,1	91
	600	7,4	74
	800	6,4	64
	1000	5,7	57

FAQ 14: How do the sizes of the indentations produced by the various portable hardness testers compare?

In general, the larger the area sampled by an indentation the more consistent the test results. Variations in microstructure of non-homogeneous materials or those comprised of large coarse grains are averaged providing consistent results. Another advantage of a larger indentation is less demand is placed on the surface finish thereby reducing the time for preparing the surface.

In comparison, the indentations yielded by the various impact devices of rebound testers are much larger than those created by any UCI probe. When testing large castings and forgings the rebound tester is recommended. Testing small components comprised of homogeneous materials or those having received surface hardening processes require the shallower indentations produced by UCI probes.
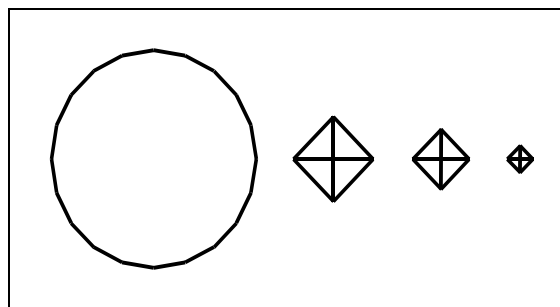
Comparison of indentation width for Dyna D impact device and MIC 2010, MIC 205, MIC 201probe

The tables below are provided to compare the indentation width and depth of rebound impact devices and UCI probes at three levels of hardness.

	Dyna G 6 mm ball, 90 N mm	Dyna D 3 mm ball 11 N mm	MIC 2010 98 N	MIC 205 50 N	MIC 201 10 N	MIC 2103 3 N
64 HRC		350	152	107	48	25
55 HRC	898	449	175	124	56	28
30 HRC	1030	541	249	175	79	41

Approximate indentation width (in μm) at different hardness levels.

	Dyna G 6 mm ball, 90 N mm	Dyna D 3 mm ball 11 N mm	MIC 2010 98 N	MIC 205 50 N	MIC 201 10 N	MIC 2103 3 N
800 HV		16	22	16	7	4
600 HV	63	28	25	20	9	5
300 HV	83	35	35	25	11	6

Approximate indentation depth (in μm) at different hardness levels.

FAQ 15: What is an effective method to measure the HAZ on welded parts?

Hardness measurements in the HAZ determine whether the welding was done properly or if a post weld heat treatment is required. Limitations must be placed on the hardness of the base metal, heat-affected zone (HAZ) and weld metal. If too hard, they will not have sufficient ductility for the service conditions, or their corrosion resistance may be impaired.

The HAZ may only be 3mm wide and contains several zones differing metallurgically. Therefore a small indention is desirable to detect the narrow band of the hardened areas. Performing a Brinell test or even using the Telebrineller (commonly used in refineries) results in quite a large indentation that averages several zones. This would mask the presence of this undesirable condition.

This is an excellent application for the MIC 10 in combination with either the MIC-205 or MIC-2010 probe due to their design and the small indentations they create. With the diamond protruding from the probe sleeve the operator can precisely position it. The small indentations produced make it possible to detects the undesirable condition so that a post weld heat treat can be used to correct the problem.

A MIC-227 test support is also available to accurately index across the pipe to record the hardness progression.