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# Metallic materials — Instrumented indentation test for hardness and materials parameters —

## Part 5: Linear elastic dynamic instrumented indentation testing (DIIT)

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# Foreword

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This document was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 3, *Hardness testing*.



A list of all parts in the ISO 14577 series can be found on the ISO website.

— *Part 1: Test method*

— *Part 2: Verification and calibration of testing machines*

— *Part 3: Calibration of reference blocks*

— *Part 4: Test method for metallic and non-metallic coatings*

— *Part 5: Linear elastic dynamic instrumented indentation testing (DIIT)*

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

 

# Introduction

Hardness has typically been defined as the resistance of a material to permanent penetration by another harder material. The results obtained when performing Rockwell, Vickers and Brinell tests are determined after the test force has been removed. Therefore, the effect of elastic deformation under the indenter has been ignored.

ISO 14577 (all parts) has been prepared to enable the user to evaluate the indentation of materials by considering both the force and displacement during plastic and elastic deformation. By monitoring the complete cycle of increasing and removal of the test force, hardness values equivalent to traditional hardness values can be determined.

This part of ISO 14577 has been prepared to enable the user by considering the material properties indentation modulus and elasto-plastic hardness, when dynamic indentation test techniques are used to improve instrumented indentation test techniques.



 

# Metallic materials — Instrumented indentation test for hardness and materials parameters —

## Part 5: Linear elastic dynamic instrumented indentation testing (DIIT)

## 1 Scope

This part of ISO 14577 specifies the method of dynamic linear elastic instrumented indentation test for determination of indentation hardness and indentation modulus of materials showing elastic-plastic behaviour when oscillatory force or displacement is applied to the indenter while the load or displacement is held constant at a prescribed target value or while the indenter is continuously loaded to a prescribed target load or target depth.

## 2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.



ISO 14577-1, *Metallic materials — Instrumented indentation test for hardness and materials parameters — Part 1: Test method*



ISO 14577-2, *Metallic materials — Instrumented indentation test for hardness and materials parameters — Part 2: Verification and calibration of testing machines*

ISO 14577-3, *Metallic materials — Instrumented indentation test for hardness and materials parameters — Part 3: Calibration of reference blocks*

ISO 14577-4, *Metallic materials — Instrumented indentation test for hardness and materials parameters — Part 4: Test method for metallic and non-metallic coatings*

## 3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 14577-1, ISO 14577-2, ISO 14577-3 and ISO 14577-4 and in Table 1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

 

**Table 1 — Symbols and designations**

| Symbols | Designations | Unit |
|---|---|---|
| $h_{dc}$ | Depth of the contact of the indenter with the test piece at $F_{dmax}$ | mm |
| $F(h)$ | Test force at depth h | mN |
| $A_p(h_{dc})$ | Projected area of contact at distance $h_{dc}$ from the tip | $mm^2$ |
| $F_{dmax}$ | Maximum value of force oscillation | mN |
| $F_d(t)$ | Instantenious value of the oscillating force | mN |
| $h_{dmax}$ | Maximum value of displacement oscillation | nm |
| $h_d(t)$ | Instantenious value of the oscillating displacement | nm |
| $f$ | Frequency of oscillation | $s^{-1}$ |
| ω | Angular frequency of oscillation ($\omega = 2\pi f$) | $s^{-1}$ |
| $S_d$ | Dynamic stiffness (stiffness of the contact at $F_{dmax}$) | mN/nm |
| $k_s$ | Dynamic Stiffness of the indenter shaft supporting springs | mN/nm |
| $m$ | Oscillating mass (indenter and shaft) | g |
| $E_{rd}$ | Dynamic reduced modulus of the contact | GPa |
| $H_d$ | Dynamic indentation hardness | GPa |

## 4 Principle



A harmonic force or displacement oscillation with a known angular frequency, $\omega$, and maximum value, is applied to the indenter being in contact with the specimen during loading and/or any holding period. Commonly the force, $F_d(t)$ Formula (1), is controlled while the resulting displacement, $h_d(t)$ Formula (2), is measured. The transfer function $F_{dmax}/h_{dmax}$ can be determined simultaneously during the test or post-test.

$$F_d(t) = F_{dmax} \sin(\omega t) \quad (1)$$

$$h_d(t) = h_{dmax} \sin(\omega t) \quad (2)$$

NOTE Because this standard applies only to linear elastic deformation, Formula (1) and Formula (2) are not taking into account any phase difference. In case of materials showing visco elastic-material behaviour, a phase difference $\Delta\varphi$ between the phase angles of the displacement, $h_d(t)$ relative to the force, $F_d(t)$ can be observed.

To calculate the dynamic stiffness of the contact $S_d$, the kinematic behaviour of the sample and the actuator is modeled by a simple harmonic oscillator moving in one direction (Figure 1). This model describes only pure elastic material behaviour. The dynamic characteristics of the actuator, dynamic stiffness of the indenter shaft supporting springs, $k_s$, instrumented damping coefficient as functions of the frequency f and the oscillating mass m of the actuator (indenter plus shaft), must be known and are assumed to be constant. The mass of the sample volume influenced during oscillation must be negligible in comparison to the moving mass-of the instrument.

 

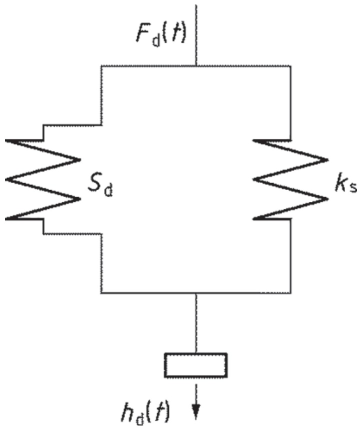


**Figure 1 — Kinematic l model of tip specimen interaction including dynamic behaviour of the instrument**

Applying this model, the magnitude of the transfer function $F_{dmax}/h_{dmax}$ is given by Formula (3).

$$\frac{F_{dmax}}{h_{dmax}} = S_d + \left(k_s - m\omega^2\right) \quad (3)$$

If the value of the transfer function is known, the dynamic contact stiffness, $S_d$, can be calculated Formula (4).



$$S_d = \left|\frac{F_{dmax}}{h_{dmax}}\right| - \left(k_S + m\omega^2\right) \quad (4)$$



## 5 Testing machine

**5.1** The testing machine shall be able to drive the actuator with a constant frequency and amplitude of force or displacement with simultaneously measuring the resulting dynamic displacement or force. This may be done directly from the measured oscillation or by using a phase-lock amplifier.

**5.2** The testing machine shall be calibrated according to ISO 14577-2 and shall be calibrated for the measurement of dynamic force, dynamic displacement and frequency.

For the direct calibration of the measurement of dynamic displacement an interferometer working at GHz can be used. For the direct calibration of the measurement of the dynamic force an interferometer or a calibrated Atomic Force Microscopes (AFM) can be used. For daily verification of the testing machine a bridge dynamic capacity or micro-electro-mechanical systems (MEMS) can be used.

If dynamic displacement and force are measured using a phase-lock amplifier the measurement of dynamic force and dynamic displacement can be calibrated by comparison of the dynamic and static signal measured for a reference sample at high sampling rates.

NOTE Using a phase-lock amplifier usually averaged values, usually root mean square values for dynamic displacement and force will be measured.

**5.3** The testing machine shall be configured in a manner that compensates for additional phase differences induced by the instrument's electronics that process both the load and displacement signals. If the testing machine can account for the instrument's collective contributions to the measured phase difference, the testing machine can be validated by measuring phase during stiff contact with a linear elastic material. Possible linear elastic materials are BK7 glass, fused silica and sapphire, which are assumed to exhibit no measurable damping, because at room temperature they are simple elastic solids.

 