

# CALIBRATION OF THE IMPACT VELOCITY AT PORTABLE HARDNESS TESTING DEVICES IN ACCORDANCE WITH LEEB

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**Abstract:** MPA NRW realized a new concept for the calibration of the velocity of the impact body of Leeb hardness testers according to the standards DIN 50156, ISO/DIS 16859 and ASTM A 956. A laser vibrometer is used for the continuous measurement of velocity and time. The measuring device enables the calibration of the impact velocity of all types of Leeb hardness testers available on the market.

**Keywords:** Calibration of Leeb hardness tester, impact velocity, laser vibrometer.

## 1. INTRODUCTION

The Leeb hardness test is used as a dynamic and portable hardness testing method for testing of massive and unwieldy parts. Meanwhile a variety of devices from different manufacturers was launched after expiry of patent protection. Hardness testing according to Leeb is standardized by the series of standards DIN 50156, ISO/DIS 16859 and ASTM A 956. In Leeb hardness testing the impact body strikes the specimen surface with a certain impact velocity, penetrates into the sample and rebounds. The Leeb hardness value is defined by the ratio of the rebound velocity to the impact velocity multiplied by the factor of 1000:

$$HL = \left| \frac{v_R}{v_A} \right| \cdot 1\,000 \quad (1)$$

Utilized symbols  
HL Leeb hardness value  
 $v_R$  rebound velocity  
 $v_A$  impact velocity

The requirements for the direct and indirect calibration of testing devices for the Leeb hardness test are set in DIN 50156-2 and Annex of ASTM A 956. For indirect calibration reference blocks are used. The mass of the impact body, the radius of the indenter, the thickness of the support ring and the impact velocity of the impact body

must be calibrated directly. So far the functionality of the devices could be tested and calibrated indirectly only by using a reference indication device and a reference impact body with a traceability to the PTB because the direct determination of the impact velocity was not possible. This calibration method is currently in existence for the devices of one manufacturer only.

## 2. SET-UP OF DEVICES FOR LEEB HARDNESS TESTING

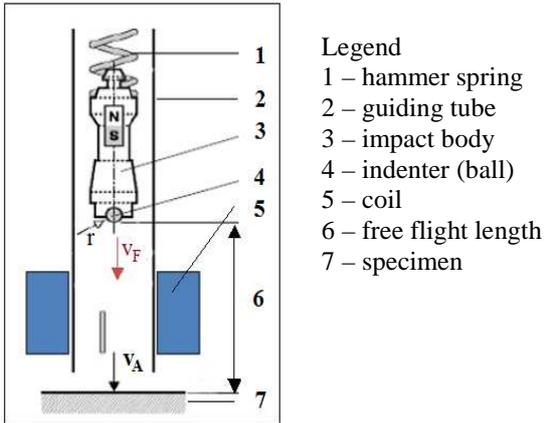
To calculate the Leeb hardness value the impact velocity and rebound velocity have to be determined. The technical implementation of the test method consists of a spring, which accelerates the impact body (with a magnet inside) - guided in a tube - to the required speed [3,4] (**fig. 1**). A coil is mounted at the guiding tube. When passing through the coil during outward and return flight the magnet induces a voltage proportional to the speed. Other construction types have multiple coils spaced at a certain distance. The determination of the velocity is calculated from the measured transit times (induction signals). By the standards [1,2,3] the impact energy, the impact velocity, the mass of the impact

Table 1: Requirements according to [1,2,3] for impact velocity

Designation	<i>Nominal value subject to type of impact device</i>		
	D/DC, S, E	C	G
Impact velocity [m/s]	2.0 – 2.2 <sup>1)</sup>	1.35–1.45 <sup>1)</sup>	2.9 – 3.1 <sup>1)</sup>
	2.05 ± 0.1 <sup>2)</sup>	1.4 ± 0.1 <sup>2)</sup>	3.0 ± 0.1 <sup>2)</sup>
	2.05 ± 1 % <sup>3)</sup>	1.4 ± 1 % <sup>3)</sup>	3.0 ± 1 % <sup>3)</sup>
Free flight length [mm]	8 ± 1 <sup>3)</sup>	8 ± 1 <sup>3)</sup>	15 ± 1 <sup>2)</sup>

<sup>1)</sup> according to DIN 50156 <sup>2)</sup> according to ISO/DIS 16859

<sup>3)</sup> according to ASTM A 956



- Legend
- 1 – hammer spring
  - 2 – guiding tube
  - 3 – impact body
  - 4 – indenter (ball)
  - 5 – coil
  - 6 – free flight length
  - 7 – specimen

**Fig. 1:** Principle of a Leeb hardness tester

The impact velocity (acceleration) results proportionately from the elastic potential energy of the spring and the potential energy in the earth's gravity field. Therefore, the normative definition of the reference direction of impact is in the direction of gravity field of the earth. When applying the hardness testing device in a direction which deviates from the direction of the gravitational field the impact direction must be specified and values must be corrected.

### 3. REQUIREMENTS FOR THE VELOCITY MEASURING DEVICE

Normatively set [1,2,3] are impact velocities between 1.4 m/s and 3.0 m/s for the different types of testing instruments. The distance for the acceleration of the impactor in the guide tube varies between 27 mm (HLD) and 47 mm (HLG). The impact body covers the last 8 mm (HLD, HLDC, HLE, HLD + 15, HLDL, HLC) or 15 mm (HLG) of the distance in free fall.

The requirements for the measuring device are:

- external and from induction voltage independent measuring system
- capability of measuring velocities between 1.0 m/s and 3.3 m/s
- measurement of the velocity of the impact body in the guide tube
- minimum velocity resolution: 0.00001 m/s
- determination of the impactor's flight distance under gravity
- triggering the impact without operator influences
- applicability for all devices available on the market.

### 4. CONSTRUCTION OF THE VELOCITY MEASURING DEVICE

In principle a direct determination of the velocity is possible by using a laser vibrometer measuring the frequency shift between emitted and reflected laser light. Therefore, a laser

vibrometer from Polytec (red light, wavelength 630 nm) with the following performance data was chosen:

- laser vibrometer laser measuring head OV 353 / controller OFV 5000
- resolution: 1 m/s/V at maximum 10 V
- resolution of the velocity:  $1 \cdot 10^{-6}$  m/s
- maximum velocity: 10 m/s
- maximum sample rate: 48 kHz; 21  $\mu$ s

When designing the measuring system a mechanical separation of the laser system and the mounting fixture for the impact devices was made (fig. 2). There are constructive similarities regarding the thread of the support rings of the existing equipment on the market. This is the basis for the mounting of the impact devices in the adjusting plate. Using the adjusting plate the impact body is aligned in the gravitational field. To determine the mass of the adjusting plate the recoil of separating impact body has to be taken into consideration (conservation of momentum). When the impact body separates the velocity is between 1.34 m/s and 2.95 m/s in case of masses between 3 g and 20 g and an average separating time of 0.001 s. This results in an impulse of between 4 N and 59 N. Based on that the masses of the adjusting plates of 5 kg and 10 kg were determined. The beam control of the laser onto the impact body and the adjustment of the laser beam to an optimum reflection signal are made by using a 45° deflecting mirror. Since the surfaces of the impact bodies front sides does not show sufficient reflection characteristics an affixed reflector foil is used. The mass of the reflector foil is 0.005 g. The elastic potential energy of the spring has to accelerate the added mass in addition. Regarding the rise of velocity under gravity there is no influence of mass. Taking the increased mass into consideration the systematic deviation of the impact velocity results from the energy equitation:

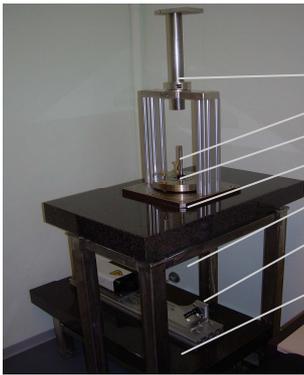
$$v_{AR} = \sqrt{\left(v_F^2 - 2 \cdot g \cdot h_F\right) \cdot \frac{m_S + m_F}{m_R + m_S + m_F} + 2 \cdot g \cdot (h_F + h_{FF})} \quad (2)$$

$$v_A = v_{AR} - \Delta v \quad (3)$$

Utilized symbols

- $h_F$  distance of spring
- $h_{FF}$  distance of free fall
- $v_{AR}$  impact velocity with reflector
- $v_F$  velocity when separating from spring
- $\Delta v$  deviation of the impact velocity
- $m_S$  mass of impact body
- $m_F$  mass of spring
- $m_R$  mass of reflector

That implies a deviation of the impact velocity of  $\Delta v(\text{HLD}) = -0.018$  m/s or  $\Delta v(\text{HLG}) = -0.008$  m/s. The triggering of the impact process is done by automatically lowering a weight on the release button of the impact device.

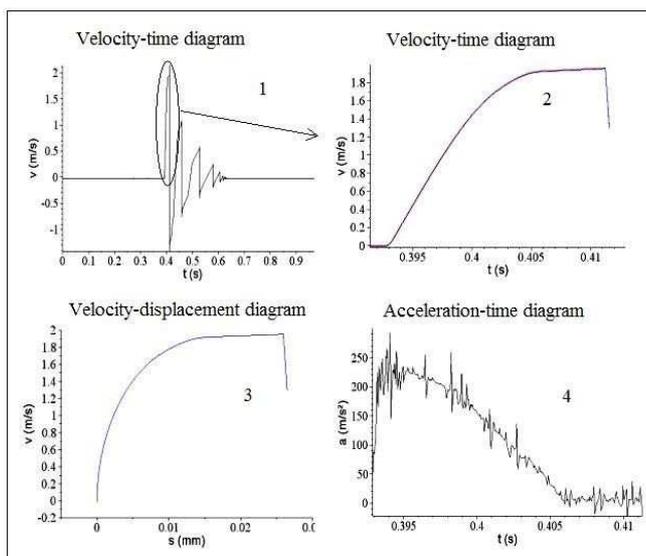


- Legend:
- weight lowering
  - Leeb impact device
  - mounting and adjusting plate
  - table for equipment mounting
  - laser
  - deflecting and adjusting mirror
  - table for laser and deflecting mirror

**Fig. 2:** Measuring device for the calibration of the impact velocity

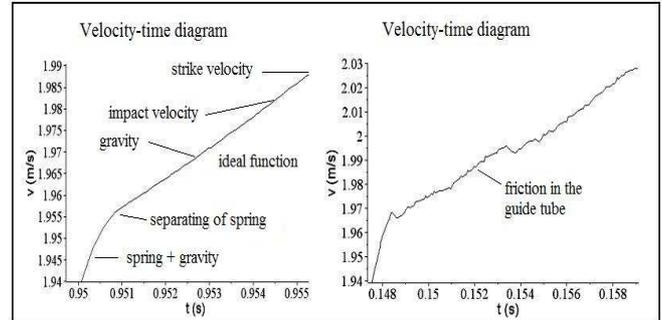
## 5. TEST PROCEDURE AND ANALYSIS

After adjusting the impact device and the beam the data recording is started. Upon reaching the pressure point on the release button the impact body is disconnected and flies, accelerated by spring force and gravity, until it reaches the stop in the adjusting plate. The velocity-time curve is recorded with a sample rate of 12 kHz and simultaneously displayed on the monitor. Subsequently, the data file is evaluated by using a special program. In the process signal noise and outliers by overdriving the electronics are selected through special filters (median filter, run and trend filter) and deleted as well as a possibly existing zero offset and the systematic deviation are corrected. Only the first velocity rise area of the curve is evaluated. The subsequent changes of velocity can be explained by dying movement of the impact body after the first impact (repeated impact and rebound). The impact velocity and the flight distance in free fall are determined when evaluating. Shown (**fig. 3**) are the original values curve (1) (velocity over time) as well as, in the selection area, the velocity over time (2), the distance over time (3) and the acceleration over time (4).



**Fig. 3:** Analysis of the calibration of the velocity of a Leeb impact device

Here, the distance is calculated by numerical integration and the acceleration using the difference quotient. The leaps in the acceleration curves can be explained by the sample rate when measuring the velocity. In addition the recording of the velocity-time curve enables the verification of friction in the guide tube.



**Fig. 4:** Velocity over time previous to impact (ideal and with friction)

To determine the free flight length the acceleration curve is evaluated (**fig. 4**). After disconnecting from the spring the impact body speeds up with local gravitational acceleration and the velocity increase is linear. Since the impact body strikes the specimen at a distance of 1 mm (HLD) or 1.5 mm (HLG) to the stop in the support ring the velocity has to be calculated back to that point. The impact velocity at the time of  $-0.47$  ms (HLD) or  $-0.50$  ms (HLG) before the stop time results from the velocity at the stop and the distance between the stop point and the theoretical point of impact.

## 6. UNCERTAINTY DURING THE CALIBRATION OF IMPACT VELOCITY

The measuring device is calibrated directly at PTB with an uncertainty of measurement from traceability of  $U_R = 0.1\%$ . The temperature and pressure dependence of the wavelength of light is compensated by the laser vibrometer (variation of environmental conditions negligible), i.e.  $U_U = 0$ . There is no operator influence on the measurement, i.e.  $U_B = 0$ . The varying mutual influence of calibration device and calibration object (e.g. by electric fields) is assumed to be negligible, i.e.  $U_W = 0$ . The uncertainty of measurement from the minimal measuring step is  $U_{ms} = 2 \cdot 10^{-6} / \sqrt{3}$  m/s. The uncertainty from the sample character of the calibration of impact devices ( $n = 10$  single measurements) is given by  $u_{KM} = s \cdot t_{(f=9, 1-\alpha=95\%)} / \sqrt{10}$  m/s ( $s$  – standard deviation,  $t$  – student factor,  $f$  – degrees of freedom,  $1-\alpha$  probability). Furthermore, the measurement uncertainties from random deviations of the mass  $U_{VAR}$  (reflector foil) and the distance impact point to stop point  $U_{h\Delta A}$ . Assuming linear independence of the terms and with  $2\sigma$  (approx. 95 %) probability the uncertainty of measurement is given by:

$$U = \sqrt{U_R^2 + U_U^2 + U_B^2 + U_W^2 + U_{ms}^2 + U_{KM}^2 + U_{VAR}^2 + U_{h\Delta A}^2} \quad (4)$$

According to this model the measurement uncertainties resulted to 0.11 % up to 0.15 % from calibrations of impact velocity performed until now.

## 7. SUMMARY AND OUTLOOK

For the first time MPA NRW realized a measuring device for the calibration of the impact velocity at testing instruments for hardness tests according to Leeb. Therefore, an external measurement and calibration of the impact velocity of the impact body in accordance with the standards [1,2,3], independent from coil principle, is possible. Furthermore, previously unsolved issues such as the influence of coupling past or foil on the momentum transfer at Leeb hardness tests can be examined with this measuring device.

## 5. REFERENCES

- 1] DIN 50156 part 1-3, Metallic materials - Leeb hardness test, 2007.
- [2] ISO/DIS 16859 part 1-3, Metallic materials - Leeb hardness test, 2013.
- [3] ASTM A 956-12, Standard Test Method for Leeb Hardness Testing of Steel Products, 2012.
- [4] D. Leeb, Zur Definition des Härtewertes „L“ beim dynamischen Messverfahren, EQUOTIP, VDI Berichte 583 Härteprüfung in Theorie und Praxis, 1986.
- [5] Konrad Herrmann et al., Härteprüfung an Metallen und Kunststoffen, Pages 83 - 91, Expert Verlag Renningen, ISBN 978-3-8169-2550-7, 2007.