

Leeb Hardness Standard with Laser Measuring

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Abstract: The paper describes the principle, structure and performance of a Leeb Hardness Standard with Laser Measuring (HLS_{laser}). The range of the standard is (200~900)HL. At the same time, uncertainty of the standard has been evaluated, of which relative expanded uncertainties ($k=2$) are at range of 1.0%~1.2%. It has been done to make comparison of HL values tested by the standard and by six HL testers made by EQUOTIP Company of Switzerland with 6 HL blocks manufactured by the same company.

Keywords: Leeb hardness standard, laser, Doppler, uncertainty.

0. GENERAL

Leeb hardness testing method was invented by Dr. Leeb in Switzerland at the end of 1970s, and has turned out to be a major breakthrough for hardness testing technology. The portable hardness tester (refer to Fig. 1) developed can be applied at different positions of the parts and components over a wide testing range for it being compact and delicate, which is suitable for the testing hardness of the components with large scale and heavy-duty as well as those which have already been installed and cannot be disassembled. Since it can not only measure Leeb hardness value, but also convert Leeb hardness value into Brinell, Vickers, Rockwell, Shore hardness value, etc., it is especially suitable for the field testing. There is a wide application in the market all over the world. However, until up to now indirect quantity transmission based on static conversion from Vickers hardness is always adopted internationally in terms of the traceability for Leeb hardness measurement. Due to there is static and dynamic distinction between the principles of the two testing methods, certain conversion errors are always existed in the hardness transmission. Therefore it always remains for the hardness professionals to concern and study on how to realize the direct recurrence and transmission of Leeb hardness measurement value based on the definition. The Leeb hardness standard with laser measuring developed by us has just turned this wish into reality.

1. LEEB HARDNESS STANDARD WITH LASER MEASURING

1.1 Operating Principle

Fig. 1 shows the outline of the standard. The operating principle of the unit is to release the D-type impactor which has potential energy of 11N•mm (or G-type impactor being potential energy of 90N•mm) in the way of free falling body, and measuring the impact velocity and rebound velocity of it by laser Doppler velocimeter in order to calculate the residue energy to be left on the impactor upon the rebounding which is represented as HLD or HLG “quantity” in terms of Leeb hardness.



Fig.1. Outline of the Leeb Hardness Standard

1.2 Major Components

The unit is an automatic measurement device integrating optical, mechanical, electrical, computer system, which consists of host, impact body, electric control system, laser Doppler velocimeter, data collecting and processing system, etc. Fig. 2 shows the schematic drawing of structure.

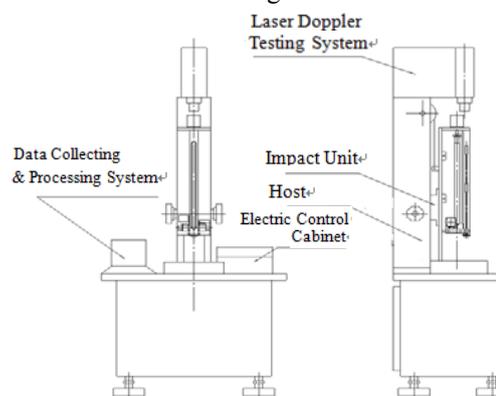


Fig. 2 Schematic Drawing of the Structure

The host consists of pedestal, workbench, lifter & guide rail, clamp for impactor, handwheel, etc. The pedestal weighs about 400kg, which is secure and stable to satisfy the dynamic testing requirement of Leeb hardness. The lifter and clamp are used to release D-type and G-type impactor, which can utilize to verify HLD and HLG scale respectively in accordance with Leeb hardness. Fig. 3 shows the schematic drawing of specialized impactor. The impactor has weight of $5.5g \pm 0.05g$ for D-type, and $20g \pm 0.05g$ for G-type which are made of tungsten carbide as ball head with diameter of $\varnothing 3mm$ and $\varnothing 5mm$ respectively.

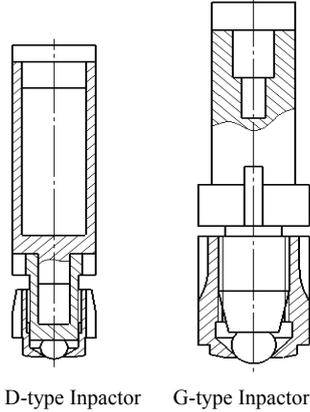


Fig.3. Schematic Drawing of Impact Unit

Laser Doppler velocimeter system is used to measure the hardness. It mainly consists of laser, spectroscope, receiver, etc. It uses Bragg cell to realize the judgment of velocity direction in order to track and measure the velocity of the impactor in the course of falling and rebounding. Its diagram of optical pathway refers to Fig. 4. The low frequency signals which can be detected by photoelectric cell are shown as follow.

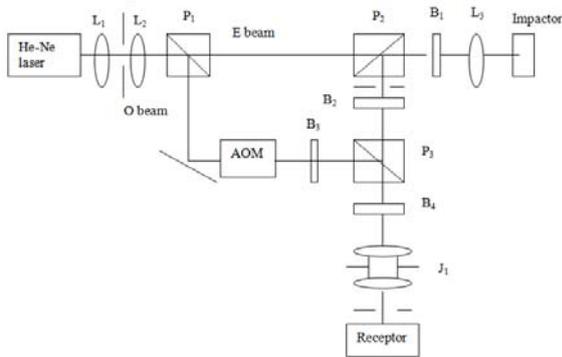


Fig. 4. Optical Path Diagram of Laser Doppler Velocimeter System

E beam-horizontal polarized; O beam-vertical polarized; P_1, P_2, P_3 -polarization beam splitters; B_1, B_2, B_3, B_4 -1/4 wave plates; L_1, L_2, L_3 -lenses; AOM (the frequency shift value is 32M); J_1 -amplification.

The current received by the receptor is associated with some factors showing as equ. (1).

$$I = \frac{1}{2} (\sin 2\alpha_1 \cdot AB \cdot \sin [2\pi (\Delta f_d - \Delta f_r) t + (\phi_{m1} - \phi_{r1})]) \quad (1)$$

Where: I — current, A;

α_1 — A beam phase, rad;

A, B — light intensity of A, B beam,

cd;

$\Delta f_d - \Delta f_r$ — frequency difference, Hz;

t — time, s;

$\phi_{m1} - \phi_{r1}$ — phase difference, rad.

The data collecting system of the unit adopts digital storage oscilloscope, the sampling rate which can reach as high as 1G/s/4CH. For the original Doppler signals being collected (refer to Fig.5), proper data processing shall be followed as illustrated by fig.6. in order to acquire the velocity signals and hardness values. The velocity curve is obtained as Fig. 7.

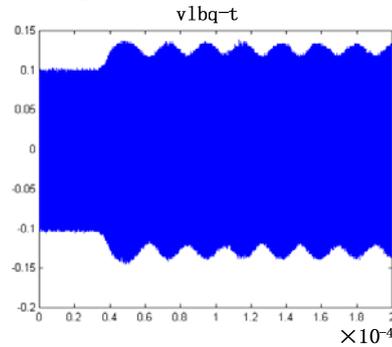


Fig. 5. Original Doppler Signal

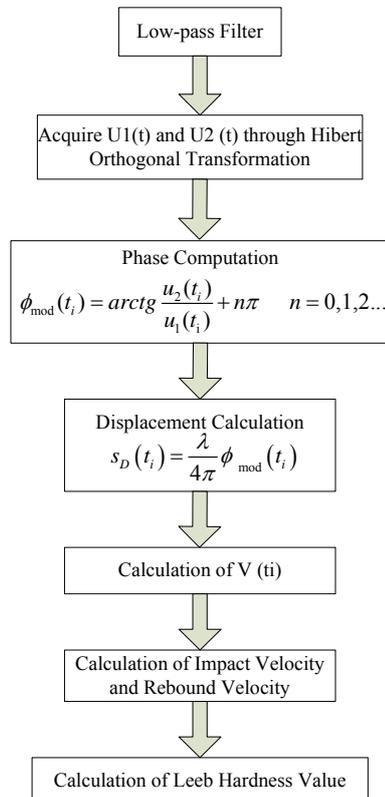


Fig. 6. Flow Diagram of Signal Processing

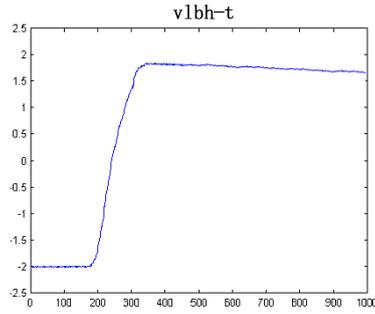


Fig. 7. Velocity Signals

2. MAJOR TECHNICAL SPECIFICATIONS AND TEST VERIFICATION

2.1 Major technical specifications

- 1) Hardness Range: (200~900)HL
- 2) Repeatability : $\leq 0.5\%$
- 3) Expanded relative uncertainty ($k=2$): (750~830)HLD: $W_{HLD}=1.0\%$; (490 ~ 570)HLD: $W_{HLD}=1.2\%$; (560~640)HLG: $W_{HLG}=1.1\%$.

2.2 Uncertainty evaluation

According to the principle of Leeb hardness test, the mathematical model of it is as equ.(2).

$$HL = 1000 \times \frac{v_R}{v_A} + \delta_e + \delta_r + R \quad (2)$$

Where, v_R — Rebound Velocity

v_A — Impact Velocity

δ_e, δ_r — The errors introduced by impact energy and spherical curvature radius of impactor.

R — Reproducibility of the standard.

The relative combined uncertainty w_{HL} of the HL is calculated as equ.(3),

$$w_{HL} = (w_{v_R}^2 + w_{v_A}^2)^{1/2} + w_e + w_r + w_R \quad (3)$$

where w_{v_R} — relative combined uncertainty of v_R

w_{v_A} — relative combined uncertainty of v_A

w_e, w_r, w_R — relative uncertainty

responsible to the e, r and R respectively.

As for v_A and v_R are obtained from a same velocity measurement curve, all the effect to uncertainty of measurement result are introduced by velocity measurement.. The table 1 has given the

budgets of the combined uncertainty for v_A or

v_R . Table2 has given the evaluation results on

w_{HL} and relative expanded uncertainty $W_{HL}, k=2$, confidence level being approx. 95%.

2.3 Test of Collateral Evidence

Test of collateral evidence is carried out as following:

- It is used that six HL hardness testers manufactured by EQUOTIP Company of Switzerland, which consists of four sets of EQUOTIP and two sets of EQUOTIP2, and the HLS_{laser}.
- It is used that 6 Leeb hardness blocks manufactured by EQUOTIP Company.
- Punching five points on each block by the six testers and the HLS_{laser} separately.

The table 1 Budgets of the combined uncertainty

No.	Sources of Uncertainty	Sensitivity Coefficient	Evaluation Method	Influence value	Distribution	Standard Uncertainty
1	velocity measurement v	1	B	1×10^{-7}	Normal, $k=1$	1×10^{-7}
			B	0.0026%	Rectangular	0.0015%
			B	0.45%	Normal, $k=1$	0.45%
2	Impact Energy of Impactor e	1	B	*0.12% **0.21% ***0.10%	Rectangular	*0.07% **0.12% ***0.06%
3	Spherical Curvature Radius of Impactor r	1	B	*0.26% **0.52% ***0.48%	Rectangular	*0.15% **0.30% ***0.28%
4	Reproducibility of standard	1	A	*0.11% **0.16% ***0.10%	/	*0.11% **0.16% ***0.10%
Remarks: *(750~830)HLD; ** (490~570)HLD; *** (560~640)HLG						

Table2 Evaluation results

Range	w_{v_A}	w_{v_R}	w_e	w_r	w_R	w_{HL}	$W_{HL} \quad k=2$
(750~830)HLD	0.33%	0.33%	0.07%	0.15%	0.11%	0.51%	1.0%
(490~570)HLD	0.33%	0.33%	0.12%	0.30%	0.16%	0.59%	1.2%
(560~640)HLG	0.33%	0.33%	0.06%	0.28%	0.10%	0.56%	1.1%

Table3 Test Data of Collateral Evidence

Block code D1554.	HLD_{ave}	σ_{HLD}	HLS_{laser}	$HLD_{ave} - HLS_{laser}$	$(HLD_{ave} - HLS_{laser}) / HLS_{laser} \quad \%$
0105A	762.6	2.0	765.0	-2.4	-0.3
0105B	762.8	2.3	763.3	-0.5	-0.1
0103A	765.2	2.3	766.7	-1.5	-0.2
0103B	767.5	2.3	766.1	1.4	0.2
0109A	767.5	2.6	767.1	0.4	0.05
0109B	768.0	2.8	769.0	-1.0	-0.1

- Calculating the average of the six HL values tested by the 6 testers (see a column HLD_{ave} in table3), as well as its standard deviation (see a column σ_{HLD} in table3).
- Calculating deviation between HLD_{ave} and HLS_{laser} .

It could be seen that the deviation is in the range of $\pm 2.4HL$ being less than $\pm 0.3\%$ of the values HLS_{laser} , of which most are less than the standard deviation obtained by the six testers.

3. CONCLUSION

The Leeb hardness standard with laser measuring has provided a rather good interpretation for the definition of Leeb hardness through its establishment. The range of the standard is (200~900)HL. At the same time, uncertainty of the standard has been evaluated, of which relative expanded uncertainties ($k=2$) are at range of 1.0%~1.2%. The comparison of HL values shows

that the deviation between the standard and the average of HL values obtained by the 6 testers is in the range of $\pm 2.4HL$ being less than $\pm 0.3\%$ of the values HLS_{laser} .

Reference:

- [1] DIN 50156-1 (2007-07) Metallic Materials - Leeb Hardness Test - Part 1: Test Method.
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