*HARDMEKO 2004*
*Hardness Measurements Theory and Application in Laboratories and Industries*
*11-12 November, 2004, Washington, D.C., USA*

# Calibration of Portable Brinell Hardness Testers

Yuhong Li, Wansheng Li

Shandong Institute of Metrology, Jinan, 250014, China

**Abstract** - The paper describes calibration method of portable Brinell hardness testers, which have been manufactured for many years and used popularly in China, especially used in testing hardness of ferrous metals.

A series of experiment have been done concerning hardness levels for calibration, thickness of hardness blocks, supports of the blocks, diameters of ball indenters and touch-method between the block and the support. Based on result obtained from tests mentioned above, it is given that specifications of portable Brinell hardness testers including indication error of ±7%, repeatability of 4%, etc.

Besides that, this paper, also, provide an equation of Brinell values vs indentation diameters based on a table, which could be useful for application of the testers.

**Keywords**: Brinell hardness，relative deviation，portable hardness tester

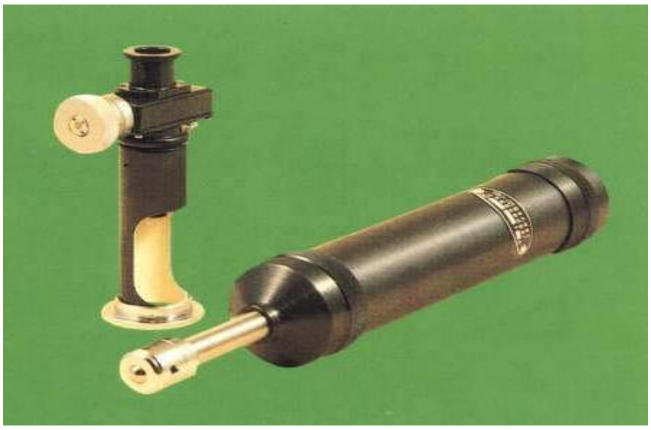
## 1. INTRODUCTION

The portable Brinell hardness tester (following called PB tester for short) shown in Fig. 1 is an instrument to measure Brinell hardness of a metal using impact force. The testing principle of PB test is that the steel ball indenter is penetrated into the surface of the measured object and obtains an indentation, which is shot by elastic-force of a spring fixed in the tester. Table 1[1] shows the hardness value of the measured object vs the diameter of the indentation obtained. The tester is mainly used for determining the Brinell hardness value of ferrous metals whose elastic module is approximately equal to 200Gpa. Its measurement range is（100-400）HBS.

Since 1990, several hundred portable Brinell hardness testers have been produced in China each year. It is arisen that how to calibrate the testers. In order to solve its calibration method, series of experiments have been carried out, which includes hardness levels for calibration, thickness of hardness blocks to be used in calibration, support of the blocks, diameter of ball indenters and touch-method between the block and support. Based on results obtained from tests mentioned above, it is given that specification of PB tester, calibration method and requirement of reference blocks used in the calibration.

Besides that, this paper, also, provide an equation of the Brinell values vs indentation diameters based on table 1, which could be useful for application of the testers.

Fig. 1. Photograph of a portable Brinell hardness tester



## 2. REQUIREMENT FOR PB TESTER [2]

It is the first thing to determine main technical specifications for a portable Brinell hardness tester, which shall be reasonable and meet requirement of users. Based on the experiments carried out and others associated, the main specifications of the PB testers are shown as follows.

- Diameter of a steel ball as an indenter shall be (10 ±0.01) mm
- The ball shall be fixed in its ball-holder tightly without releasing. Part of the ball above the ball-holder shall not be less than a quarter of the ball diameter, which is 2.5 mm.
- Measurement unit:
  - Amplification rate shall be accurate as ±0.006 mm within 6 mm measuring length.
  - Indication error shall be less than or equal to ±0.01 mm.
  - Indication error for decreasing measurement shall be less than or equal to ±0.005 mm
- Permitted indication error of PB tester shall be within ±7.0%.
- Repeatability of PB tester shall be less than or equal to 4.0%.

TABLE 1. Brinell hardnes vs diameter of indentation penetrated by PB tester

| Diameter (mm) | Hardness (HBS10/3000) | $I_p$ | Diameter (mm) | Hardness (HBS10/3000) | $I_p$ | Diameter (mm) | Hardness (HBS10/3000) | $I_p$ |
|---|---|---|---|---|---|---|---|---|
| 2.72 | 404 | -5.4E-03 | 3.10 | 242 | 2.3E-03 | 3.48 | 153 | -1.2E-03 |
| 2.74 | 393 | -4.9E-03 | 3.12 | 236 | 1.9E-03 | 3.50 | 149 | 1.9E-03 |
| 2.76 | 382 | -3.6E-03 | 3.14 | 230 | 2.2E-03 | 3.52 | 145 | 5.7E-03 |
| 2.78 | 371 | -1.4E-03 | 3.16 | 225 | -1.0E-03 | 3.54 | 141 | 1.0E-02 |
| 2.80 | 361 | -1.1E-03 | 3.18 | 220 | -3.7E-03 | 3.56 | 137 | 1.6E-02 |
| 2.82 | 351 | -3.1E-05 | 3.20 | 215 | -5.6E-03 | 3.58 | 133 | 2.2E-02 |
| 2.84 | 341 | 1.9E-03 | 3.22 | 210 | -6.9E-03 | 3.60 | 130 | 2.1E-02 |
| 2.86 | 331 | 4.8E-03 | 3.24 | 205 | -7.4E-03 | 3.62 | 127 | 2.0E-02 |
| 2.88 | 322 | 5.6E-03 | 3.26 | 200 | -7.3E-03 | 3.64 | 124 | 2.0E-02 |
| 2.90 | 313 | 7.2E-03 | 3.28 | 196 | -1.1E-02 | 3.66 | 121 | 1.9E-02 |
| 2.92 | 305 | 6.4E-03 | 3.30 | 191 | -9.8E-03 | 3.68 | 118 | 2.0E-02 |
| 2.94 | 297 | 6.4E-03 | 3.32 | 187 | -1.3E-02 | 3.70 | 116 | 1.1E-02 |
| 2.96 | 289 | 7.2E-03 | 3.34 | 182 | -9.6E-03 | 3.72 | 113 | 1.2E-02 |
| 2.98 | 282 | 5.3E-03 | 3.36 | 178 | -1.1E-02 | 3.74 | 110 | 1.3E-02 |
| 3.00 | 275 | 4.1E-03 | 3.38 | 173 | -6.5E-03 | 3.76 | 108 | 3.9E-03 |
| 3.02 | 268 | 3.7E-03 | 3.40 | 169 | -6.7E-03 | 3.78 | 106 | -4.9E-03 |
| 3.04 | 261 | 4.1E-03 | 3.42 | 165 | -6.3E-03 | 3.80 | 104 | -1.4E-02 |
| 3.06 | 254 | 5.4E-03 | 3.44 | 161 | -5.3E-03 | 3.82 | 102 | -2.4E-02 |
| 3.08 | 248 | 3.5E-03 | 3.46 | 157 | -3.6E-03 | 3.84 | 100 | -3.4E-02 |

## 3. CALIBRATION METHOD

It could be done by means of length measurement instruments to calibrate diameter of the steel ball, part of the ball above the ball-holder and the measurement unit, which is omitted here.

Three levels of Brinell hardness blocks are chosen to calibrate the PB tester being (100-150)HBS10/3000, (200-250)HBS10/3000 and (350-400)HBS10/3000, which are required being uniformity of 3.0 % and long-term stability of 1.5% per year.

Note: In the near future, HBS10/3000 will be replaced by HBW10/3000, since China verification regulation for Brinell hardness will change HBS into HBW for all Brinell hardness scales following ISO 6506 1999 [3].

Traceability of the PB tester is shown in Fig.2. It could be evaluated that relative hardness uncertainty of reference blocks and relative uncertainty of hardness obtained on the reference block penetrated by the PB tester.

Assuming hardness relative uncertainty of a Brinell hardness standard machine used is 1% (k=2) [4], and non-uniformity of a reference block penetrated by the standard machine is 2%, which is maximum value required in ISO 6506 1999, then relative uncertainty of hardness obtained on the reference block penetrated by standard machine could be calculated as below [5],

$$w_b = \sqrt{(\frac{0.01}{2})^2 + (\frac{0.02}{\sqrt{3}})^2} = 1.3\% \quad (1)$$

Expanded uncertainty of hardness obtained on the reference block penetrated by the standard machine is given by

$$W_b = 3.0\% \qquad k=2$$

If it is assumed that maximum deviation is 3% of table 1 to obtain Brinell hardness value on the reference block penetrated by the PB tester, and repeatability of the value obtained by the tester is 4%, then

Relative uncertainty of hardness value obtained on the reference block penetrated by the tester could be that

$$w_{pb} = \sqrt{(\frac{0.03}{\sqrt{3}})^2 + (\frac{0.04}{\sqrt{3}})^2} = 2.9\% \quad (2)$$

Thus, the expanded uncertainty of hardness value obtained on the reference block penetrated by the tester is given by

$$W_{pb} = 6.0\%$$

Table 2 shows calibration example of the PB tester, which includes data for diameters of indentations penetrated on the reference blocks by the PB tester, average of diameters measured, hardness obtained from table 1, repeatability of the hardness, indication error of the hardness tested from standard value, and standard uncertainty of the hardness as well as its expanded uncertainty (k=2).

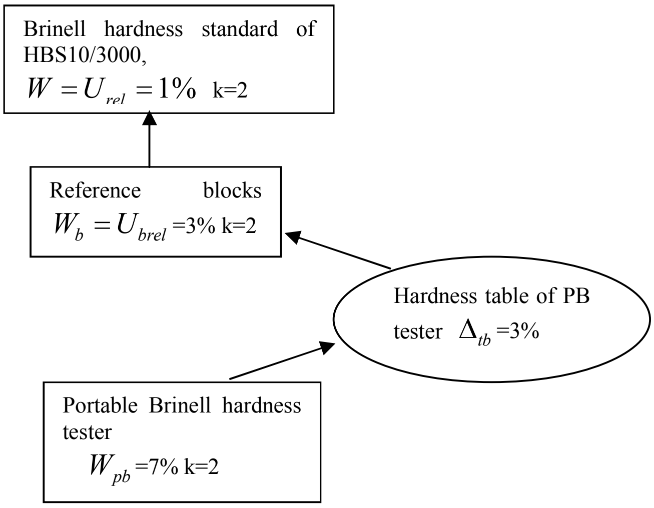



Fig. 2. Traceability of Portable Brinell hardness tester

TABLE 2. Calibration example of PB tester

| Standard block value HBS10/3000 | Diameter penetrated by tester mm | | | Average mm | Hardness HBS10/3000 | Rep. % | Ind. error % | $w_{pb}$ % | $W_{pb}$ % |
|---|---|---|---|---|---|---|---|---|---|
| 129 | 3.65 | 3.65 | 3.65 | 3.65 | 122 | 0.0 | -5.4 | 1.8 | 3.6 |
| 220 | 3.19 | 3.19 | 3.20 | 3.19 | 218 | 1.1 | -0.9 | 1.8 | 3.6 |
| 388 | 2.74 | 2.74 | 2.74 | 2.74 | 393 | 0.0 | 1.3 | 1.8 | 3.6 |

## 4. EXPERIMENT FOR CHOOSING SPECIFICATIONS OF PB TESTER

In order to determine the specification of the PB tester and to choose suitable calibration methods, five kinds of experiments have been done concerning hardness levels for calibration, thickness of hardness blocks, supports of the blocks, diameters of the ball indenters and touch-method between the block and the support.

### *4.1. Hardness blocks*

It could be seen from table 3 and fig.3 that

(1) Repeatability for all testers is less than 1.5%;
(2) Relative deviation of block HBS10/1000 is positive being range of (1.0-7.1)%;
(3) Relative deviation of blocks HBS10/3000 is negative being range of -(0.9-5.9)%;
(4) Other ten testers have been tested, which obtained similar results.

Based on the results obtained above, three reference blocks are chosen for calibration of the PB tester, and measuring range of the PB test is from 100HBS10/3000 to 400HBS10/3000, which is in compliance with the law of Brinell hardness ($F/D^2$=constant). At the same time, the indication error of the PB tester is required less than or equal to ±7.0% and its repeatability less than or equal to 4.0%.

Fig.4 show that

(1) The relative deviation is trendy to less with thickness of blocks becoming thicker;
(2) The thickness effect could be ignored when it is equal to or bigger than 22 mm.

Since then, the thickness of the standard blocks is Chosen as (23±1) mm.

### *4.2. Support of blocks*

It could be seen in fig. 5 that Relative deviation with an iron support is quite less than that with a floor, which is caused due to impact energy absorbed by the floor directly since the block is less weight and volume. Therefore, iron-support was chosen and its size is about 300×300×200 mm.

### *4.3. Touch method*

It has also affected on the relative deviation of hardness measured by PB tester from the standard one that touch-method between the block and support is directly touch or touch with Vaseline. It is shown in fig.6 that

- the maximum relative deviation of two touch methods is 5%,
- the block is harder, the effect is more significant.

In order to decrease the influence from touch-method, Vaseline is used to connect blocks and iron-support in calibration.

TABLE 3.  Experiment for selection of Brinell hardness reference blocks

| Hardness value | Relative deviation of hardness value for seven testers (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 01 | 02 | 03 | 04 | 05 | 06 | 07 |
| 99HBS10/1000 | 7.1 | 6.1 | 5.1 | 1.0 | 6.1 | 5.1 | 5.1 |
| 108HBS10/3000 | -1.9 | -2.8 | -3.7 | -2.8 | -3.7 | -3.7 | -3.1 |
| 220HBS10/3000 | -0.9 | -2.3 | -4.1 | -4.5 | -5.9 | -5.9 | -2.3 |
| 296HBS10/3000 | -5.1 | -4.7 | -4.1 | -3.4 | -3.4 | -3.4 | -3.4 |
| 428HBS10/3000 | -3.6 | -4.4 | -5.6 | -1.2 | -1.2 | -1.2 | -5.6 |
| Repeatability (%) | 1.4 | 0.1 | 1.1 | 0.1 | 1.4 | 1.4 | 0.1 |

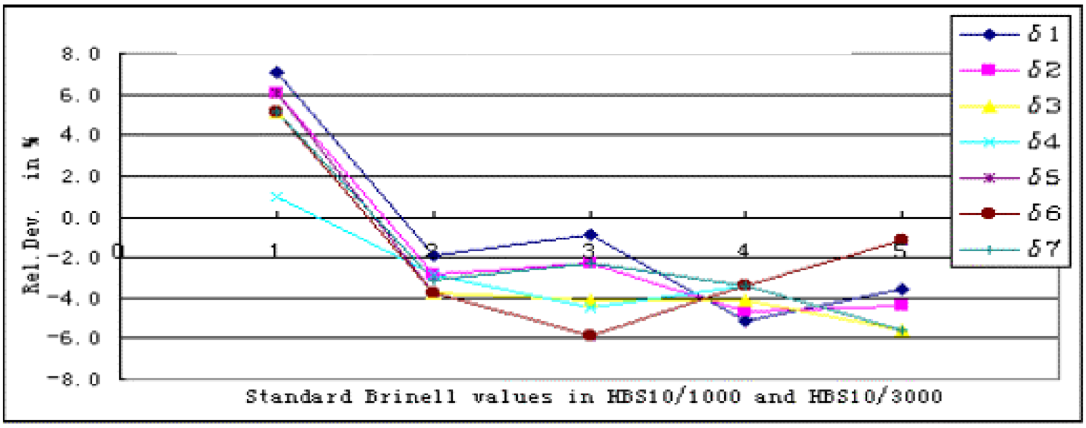



Fig.3 Rel . Dev . vs hardness value

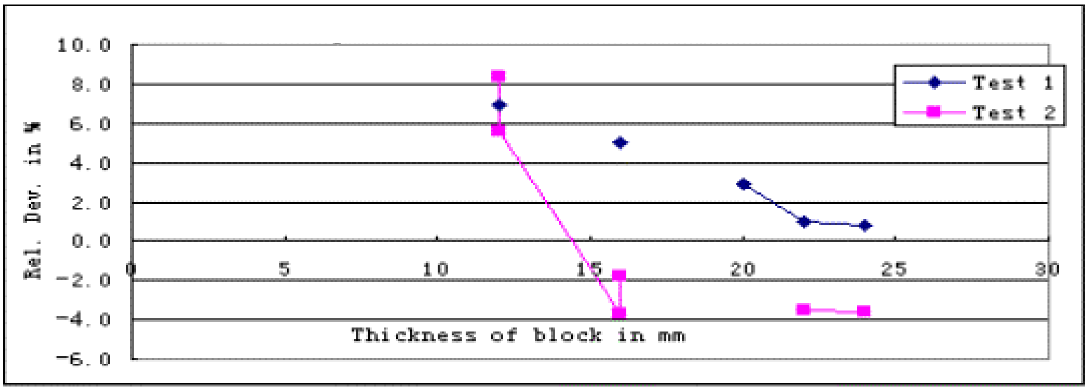



Fig.4 Relative deviation vs thickness of block

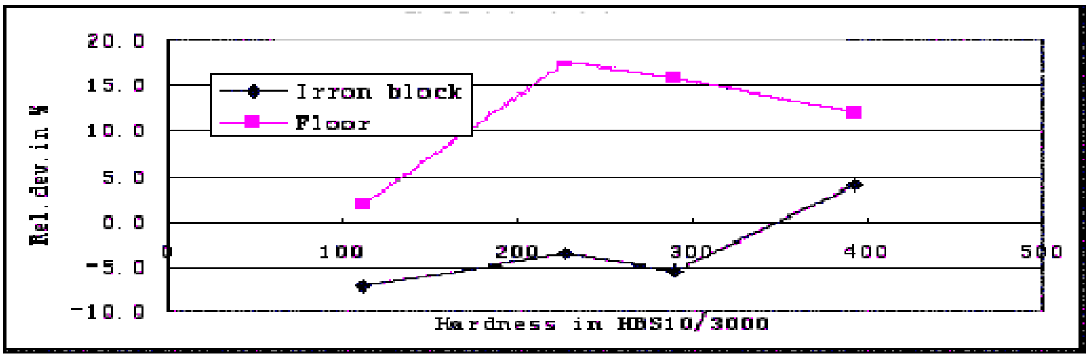



Fig.5.  Relative deviation vs supports

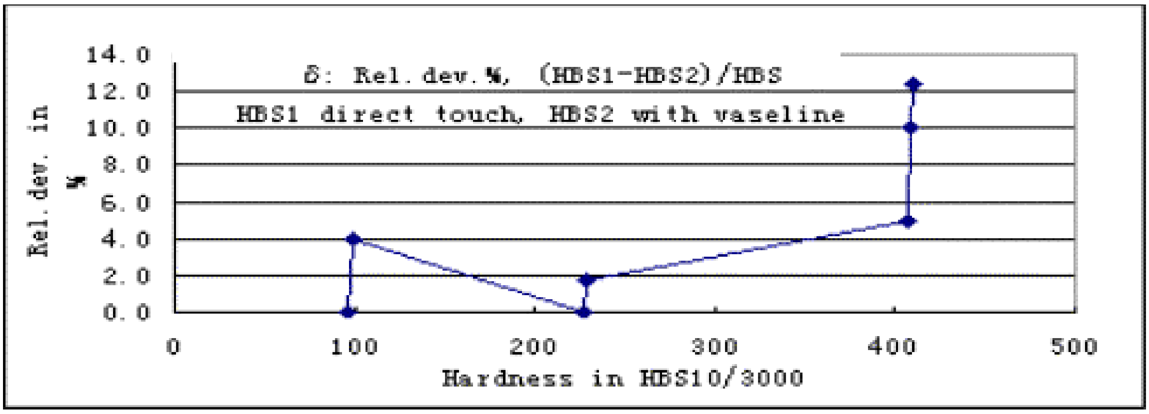



Fig.6. Relative deviation of two touch methods

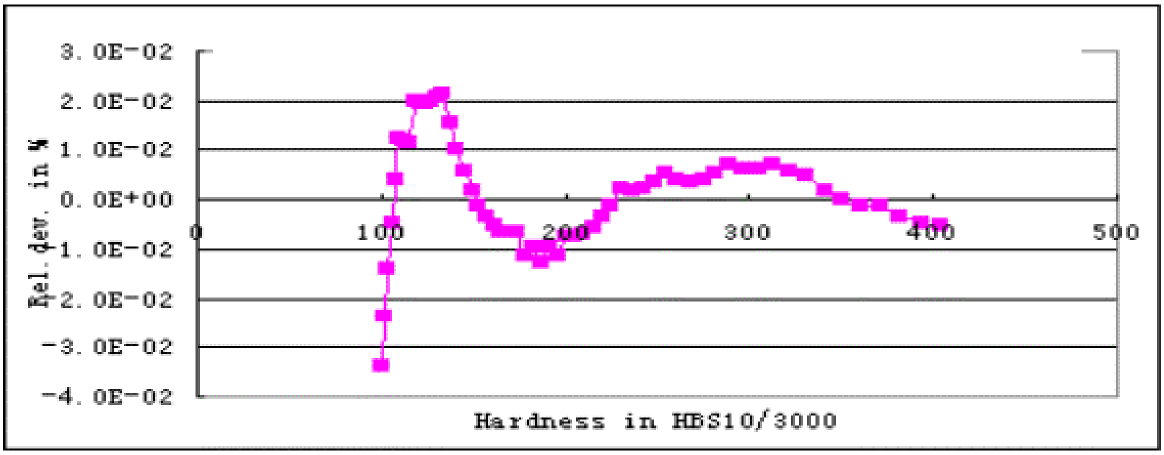



Fig.7. Relative deviation between hardness values from the table and calculated by the equation

Besides above, several equations of polynomial, exponential, power and logarithm have been fitted. After comparison of relative deviation of hardness calculated by these and that from table1, equation (3) is chosen to calculate Brinell hardness value from diameter of indentation penetrated by a PB tester. Relative deviation between both values from the table and the equation is less than 2.0% mostly, with the exception of four points, which are 102 and 100HBS10/3000 with relative deviation -2.4% and -3.4%, 133 and 130HBS10/3000 with 2.2%, 2.1%. See table 1 and fig.7.

$$HB=-118.44d^3+1342.3d^2-5218.1d+7047.7 \quad (3)$$

Where: HB is Brinell hardness value;

*d is* the diameter of indentation penetrated by a PB tester

## 5. CONCLUSION

According to the calibration method drafted, over one thousand of PB testers have been calibrated, from which some conclusions could be drawn as follows.

- It is suitable for calibration of the PB testers that the specifications and calibration method stipulated.
- The experiments carried out have made necessary base for the calibration.
- It could be done in the near future that establish a more accuracy table and equation of Brinell hardness vs diameter of indentation penetrated by PB tester by means of experiment.

## REFERENCES

[1] Д.Б.Гогоберидзе, ТВЕРДОСТЬ И МЕТОДЫ ЕЕ ИЗМЕРЕНИЯ, Машгиз, 1952
[2] JJG 870-94 Verification regulation of portable Brinell hardness tester, AQSIQ, China, 1994.
[3] ISO 6506 1999, Metallic materials—Brinell hardness test.
[4] NIM Report of establishing National standard for Brinell hardness (in Chinese), 1984.
[5] PTB/5.21 1999, Guideline to the determination of the uncertainty of the Brinell and the Vickers measuring method.

Contact person for paper: Li Yuhong, Shandong Institute of Metrology, Jinan, 250014, China. Tel: (0531) 2964400, Fax: (0531) 2964412. E-mail: sdjllyh@public.jn.sd.cn