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

HARDNESS TESTERS CALIBRATION PRACTICE

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Abstract – In the framework of the standardization and laboratory activities concerning the calibration of hardness testers, in particular for indirect verification there are some questions to be answered to decide an efficient metrological confirmation strategy:

a) how many points on each scale shall be checked?
b) How many levels of the indentation scale shall be checked?
c) How many levels of forces shall be checked?
d) Is the correlation between indirect results and direct results strong enough to allow a partial check of the hardness scales of the tester?

A number of tests have been made and the results have been statistically elaborated to give an answer to these questions.

Keywords: hardness, calibration, hardness tester

1. INTRODUCTION

Well known technical reasons require, for hardness measurement, to have both the direct and indirect calibration procedure [1]. In fact direct measurement of the main parameters of the hardness measurement cycle (forces, length scale, indenter geometry) shall guarantee that the measurement performed corresponds to the method described in standard documents, whereas the indirect measurements take care of possible deviations due to factors very difficult to be measured, as the mechanical performances of the indenter, dynamic behaviour and stiffness of the tester structure and indentation velocity of the last part of indentation cycle. For these reasons the initial qualification of a hardness tester require the application of both direct and indirect calibration procedures, to have a complete check of the tester, as the direct qualification alone cannot assure that effects of unmeasurable factors are negligible, while indirect qualification cannot avoid unacceptable adjustment of the measurement results based on the compensation of the effect of a wrong cycle parameter obtained putting out of tolerance an other parameter.

Periodic checks, on the contrary, shall guaranty only the stability of the testers; therefore possible different strategies can be adopted, always with the aim of evaluating that all the parameters, measurable and unmeasurable ones, are kept within the tolerances. Moreover even in harness measurement metrological confirmations, as commonly used for other quantities (ISO 10012), can be adopted.

The point is that to establish a good metrological confirmation strategy it is necessary to have practical experience: in particular for indirect measurement there are some questions to be answered to decide an efficient metrological confirmation strategy:

a) how many points on each scale shall be checked? (This is connected also to the linearity or interpolation error of the scale, which cannot be evaluated without the experience of measurement on a larger number of points than required by calibration standards).
b) How many levels of the indentation scale shall be checked?
c) How many levels of forces shall be checked?
d) Is the correlation between indirect results and direct results strong enough to allow a partial check of the hardness scales of the tester (for instance a main scale calibrated with direct and indirect measurement and the other scales calibrated only by indirect or indirect measurements)?

Following are presented the experimental tests and the results statistically elaborated to give an answer to these questions and, specifically for the question of linearity and interpolation error, some information has been obtained.

2. EXPERIMENTAL TESTS

Thanks to the work of two Calibration Laboratories, LTF S.p.A. and T.M.T. s.n.c., of the Italian Calibration Service SIT (Servizio di Taratura in Italia), 38 hardness testers, currently used in workshops and laboratories of industrial plants, were checked with reference hardness blocks with an extended evaluation on five hardness levels, instead of the three hardness levels required by standard specifications [2]. This exercise allows to analyse what is the typical pattern of industrial hardness testers, has, having five measurement points, it is possible to use second degree models still keeping two degrees of freedom. A comparison with regressions performed with a first degree model allow to understand if this simpler model, applicable even when only the three measurement required by standard specifications are available, is sufficient for describing the tester performance. The results obtained are given in table 1 and 2.

TABLE I. Results of HRC measurements made by LTF S.p.A.

Tester	Indenter	Hardness deviations from the mean values				
		25,04	*34,17*	*44,88*	*50,12*	*63,71*
1	129	0,36	0,23	0,22	-0,02	-0,19
2	1861	0,70	0,63	0,30	0,30	-0,11
3	G1388	-0,72	-0,63	-0,64	-0,52	0,05
4	1871	0,60	0,21	0,40	0,46	0,23
5	1613	-0,32	-0,29	-0,30	-0,06	-0,19
6	1642	0,12	0,09	0,26	0,10	-0,07
7	N375	0,08	0,15	-0,10	-0,06	-0,37
8	1613	0,34	0,63	0,28	0,44	0,05
9	1601	0,40	0,43	-0,12	0,18	-0,35
10	825	0,58	0,41	0,58	0,24	0,07
11	447	0,86	0,87	0,78	0,88	0,71
12	471	0,04	0,05	0,06	-0,16	-0,43
13	786	-0,64	-0,81	-0,74	-0,76	-0,69
14	1632	-0,26	-0,21	-0,26	-0,18	-0,39
15	251	-0,34	-0,35	-0,58	-0,76	-0,71
16	1840	0,10	0,21	0,16	0,40	0,05
17	267	-0,02	0,01	-0,08	0,02	-0,53
18	1871	0,84	0,63	0,30	0,38	0,21

TABLE II. Results of HRC measurements made by T.M.T. s.n.c.

Tester	Indenter	Hardness deviations from the mean values				
		24,90	*39,53*	*50,30*	*54,85*	*64,50*
19	8135	0,58	0,19	-0,06	-0,09	-0,90
		24,80	*39,53*	*50,20*	*54,85*	*64,50*
20	18887	0,46	0,35	0,36	0,03	0,02
21	14126	0,26	0,23	0,12	-0,07	-0,42
		24,00	*39,53*	*50,20*	*54,85*	*64,50*
22	4207	0,88	0,53	-0,18	-0,07	-0,80
23	201	-1,08	0,25	0,30	0,97	0,28
24	6207276	-0,26	0,13	0,26	0,15	-0,14
25	6359	-0,46	-0,55	-0,80	-0,91	-0,76
26	495	1,36	1,45	0,90	0,67	-0,28
27	361	-0,88	-0,59	-0,76	-0,93	-1,06
28	4326	0,06	0,19	-0,44	-1,41	-1,40
29	1277	0,32	0,79	0,36	0,61	-0,46
30	0012	-0,20	0,59	0,26	0,65	-0,04
31	6304307	-0,20	0,45	0,14	0,11	-0,18
32	5659	-0,62	-0,01	-0,14	-0,19	-0,80
33	4366	-0,70	-0,35	-0,24	-0,05	-0,26
34	1971	-0,46	0,25	-0,28	-0,57	-0,60
35	2032-2	0,42	0,59	0,12	0,29	-0,26
36	02591	0,28	0,81	0,62	0,77	0,14
37	6796	0,14	0,19	-0,42	-0,53	-0,62
38	6796	-0,12	-0,53	-1,14	-0,83	-1,34

There is no typical morphology. Frequently nearly constant pattern are ended with a rapid decease at the higher hardness, as shown in figure 1.

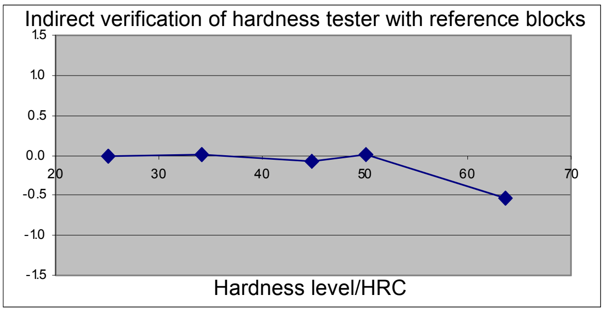

Fig. 1. Example of a common pattern characterized by a rapid decrease at the higher hardness.

Others common pattern are characterized by random deviations over a very significant bias, as shown in figure 2.

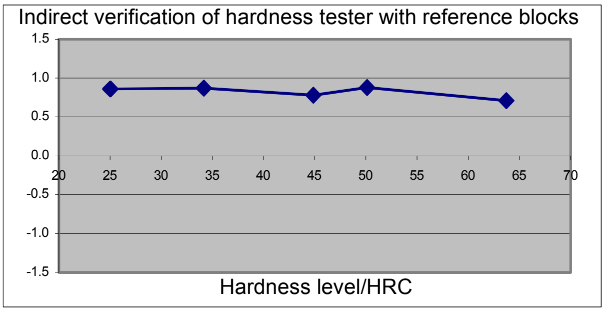

Fig. 2. Example of a nearly constant pattern over a very significant bias.

Other common shapes are well evidenced tendencies, more of linear type (first degree model, as shown in fig. 3).

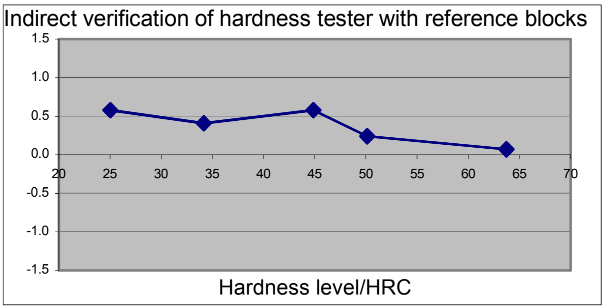

Fig. 3. Example of a linear pattern over a very significant bias.

But sometimes even clearly parabolic pattern are present, as shown in figure 4.

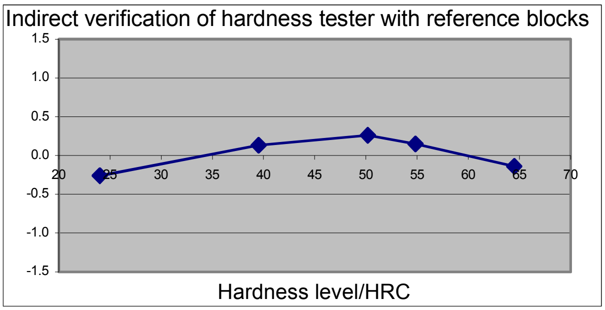

Fig. 4. Example of an evident parabolic pattern.

3. ANALYSIS OF RESULTS

To try a more objective analysis, linear regression [3] has been performed both with first degree and second-degree models. The evaluation of results was made in two ways:

- The difference of maximum residual for the first and second degree models was compared with the confidence interval of residuals to see with the method of statistical tests of hypothesis if the difference is significant
- For every hardness tester was evaluated if the standard deviation of residuals for the first degree model is greater then that obtained with the second degree model, increased by 50%, to take into account the large uncertainty of standard deviations due to the small number of degrees of freedom.

The fact that the difference is not significant against the casual variability of experimental errors can be seen also comparing the distribution of standard deviation of residuals obtained by linear regression using the two different models, as can be seen in figure 5.

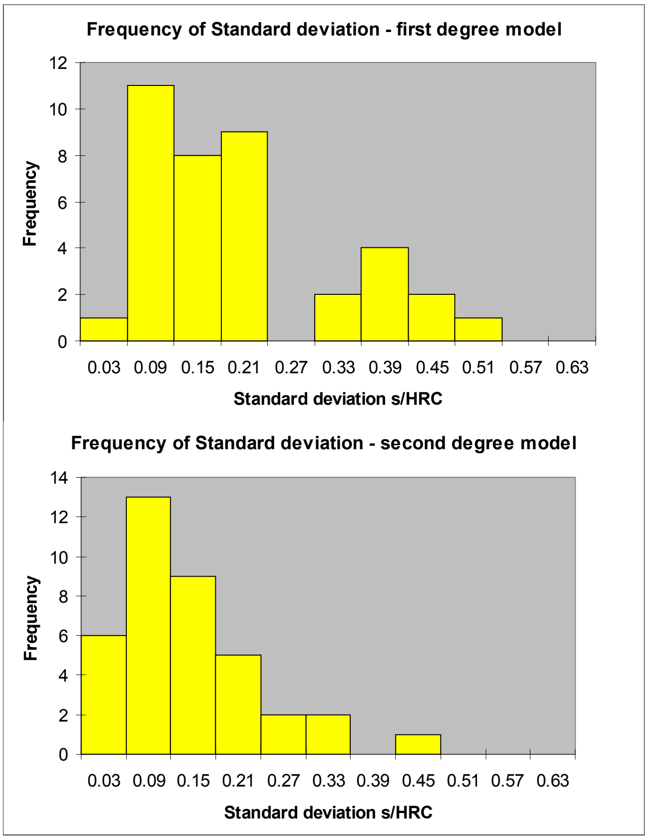

Fig. 5. Comparison of the distributions of standard deviation of residuals for the two different models of linear regression. Note the similar shape (probably in connection with a χ^2 distribution [4]) and the similar range.

3. PRACTICAL EVALUATIONS

The previous analysis has shown that the use of a first-degree model do not introduce errors larger that the normal variability of the results. This result is important because the first-degree model can be used with the results of three hardness level measurement prescribed by standard procedures. With the measurement done it is now possible to apply linear regression only to 25 HRC, 45 HRC and 65 HRC levels for checking if the fits are compatible with that obtained with five experimental points and for evaluating the amount of interpolation error. This last information, specifically, is very important to assess a typical type B uncertainty contribution to be used in the uncertainty budget.

The first check is to compare the distribution of the standard deviation against that obtained with five hardness levels. One can note from figure 6 that this distribution is even better, higher frequencies being closer to zero and the range being the same. This could be due to the fact that the number of degrees of freedom is smaller in this case.

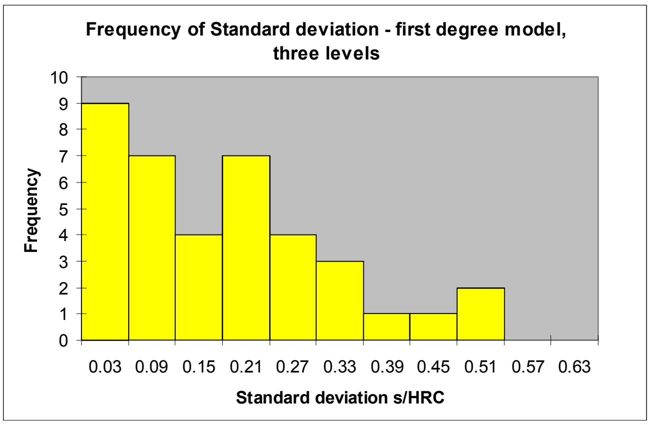

Fig. 6. Frequency distribution of the standard deviations of residual obtained with a first-degree model regression over data of three levels of hardness.

Having shown that it is statistically possible to interpolate three hardness results of normal checks, could be important now to evaluate a typical value of the interpolation error, that is the maximum of residuals. We do this evaluation both using our best information, that is the parabolic model obtained with five hardness levels, and the linear model obtained with the normal three levels, so that a further comparison can be done.

Results reported in figure 7 show that in the case of linear model over three hardness levels maximum residuals can be nearly twice as much as the maximum residuals obtained with the parabolic model ove five hardness level. In the first case the standard deviation is a little more than 0,2 HRC, while in the second case is about 0,11 HRC.

3. CONCLUSION

The experimental work done together with the data analysis have shown that there is a concrete possibility of interpolating the three hardness results of indirect measurement to define the pattern of the whole HRC scale of an hardness tester. Results thus obtained are compatible with the certainly much robust results obtained by parabolic interpolation over the results obtained on five levels of hardness.

The residual distribution, significant to establish a contribution of uncertainty for taking into account the interpolation error shows that in the first case one should consider a standard deviation of about 0,2 HRC, wile in the second case a standard deviation as low as 0.1 HRC could be acceptable.

A consideration erase immediately: the interpolation error seems to be significant for a number of applications, therefore, when critical measurement are required one should calibrate the hardness tester over five hardness levels or with a local check near to the value of hardness to be measured.

A further conclusion should be considered, that is we shall remember that this exercise has been done on the field, that is using hardness testers of any level of industrial use. In case of laboratory testers, kept carefully under control, the amount of interpolation error could be much lower.

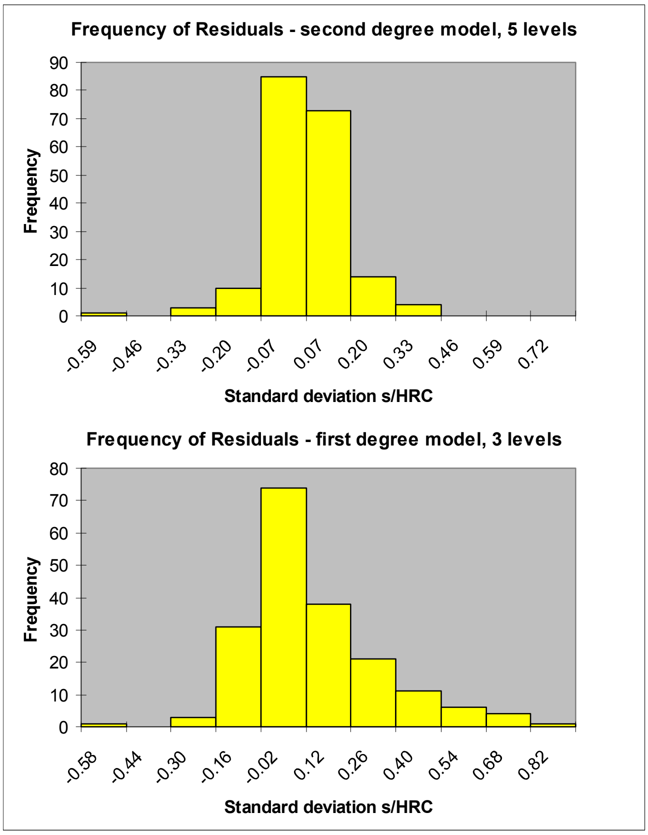

Fig. 6. Comparison of the distributions of residuals obtained using the parabolic model on five hardness levels and the linear model on three hardness levels.

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