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THE CONVERSION COEFFICIENT AND THE QUALITY OF MICRO-HARDNESS TEST

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Abstract: When the micro-hardness is measured by older, non-automated equipment, the diagonal of indentations is measured indirectly as a rule. To convert the values of the scale interval, read on the drum of measuring device is required to use a coefficient to convert the interval to the length in SI units. This paper considers the evaluation of the variability of the coefficient and its impact on the measured values of the micro-hardness. It is assumed that the value of the coefficient is stable for constant magnification of the configuration tester/microscope. The stimulus to publish this research is the fact that two operators on the same hardness tester under the same conditions determined different values of the coefficient (k). This fact followed a statistically significant difference of the measured values of the micro-hardness. In a Monte Carlo simulation, a random value is selected for each of the tasks, based on the range of estimates. The model is calculated based on this random value. The result of the model is recorded, and the process is repeated. Using the Monte Carlo method usually takes a large number of iterative runs to obtain an accurate read failure probability.
Keywords: micro-hardness, conversion coefficient, Monte Carlo method

1. INTRODUCTION

The dimension of the indentation is not read directly in units of length, but in scale divisions (d) by a device that measures the dimensions of the indentations in some older non-automated micro-hardness testers. Scale divisions (units) are read on a scale on the circumference of the drum, which controls the measuring device.The, read scale division must be multiplied by the appropriate conversion coefficient (k) to determine the actual dimension of the indentation. The size of the coefficient (k) is determined by calibration using traceable standardor gauge with defined length –the objective-micrometer. It is assumed that the value of the coefficient is stable for constant magnification of the configuration tester/microscope. The stimulus to publish this research is the fact that two operators on the same hardness tester under the same conditions determined different values of the coefficient (k). This fact followed a statistically significant difference of the measured values of the micro-hardness.

2. EQUIPMENT AND METHOD

The tester Hanemann, Mod D32 (manufactured 1988) in a configuration with microscope Neophot 32 was the equipment. The magnification of the tester is 32 $\times$ and that of indentations measuring device (eyepiece) is 15$\times$. The objective-micrometer GOST 753-55 with a nominal length L = 1 mm, divided into a hundred parts by 0.01 mm, with expanded uncertainty U = (2 +0.8 L) μm where L is the length in meters (m) and the coverage factor $k_p = 2$ was the standard. The scale was calibrated at SMU (Slovak Metrology Institute) in 2007 in accordance with the order PP 01-310-02.As can be seen in Figure 1, the indentation is "framed" by measuring device in a square (or rather the rhomb).

The distance between the lines of the objective-micrometer, which corresponded to l = 0.01, 0.02, 0.03, 0.04 and 0.05 mm were measured if the coefficient (k) was determined. Right and left tip of the square is mated with the center of relevant lines, Figure 2.

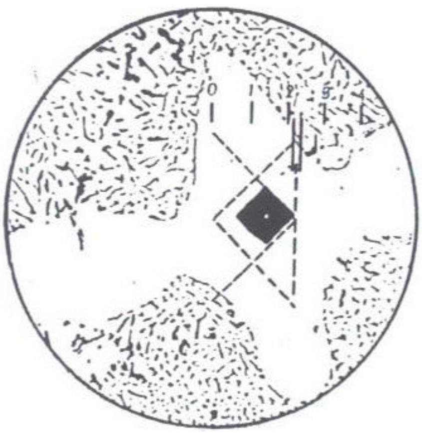

Figure 1. The diagonal of an indentation is measured used "framing".

A matching number of scale divisions (d) were read with precision of 1/10 of the division. The value of the coefficient (k) was calculated according to equation (1).

$$k = \frac{l}{d} \quad (1)$$

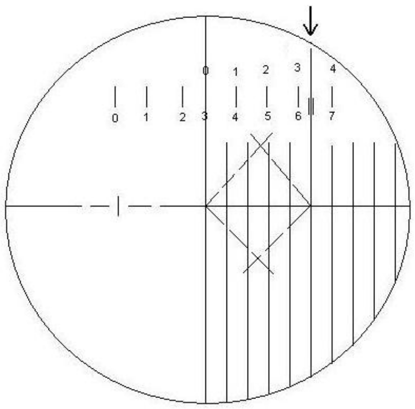

Figure 2. Determination of the coefficient (k) using objective-micrometer

Selected range of values between 0.01 and 0.05 mm corresponds to the actual values of the indentation diagonal in pure metals (for example about 0.4 mm for lead at test load 0.9807 N) [1].

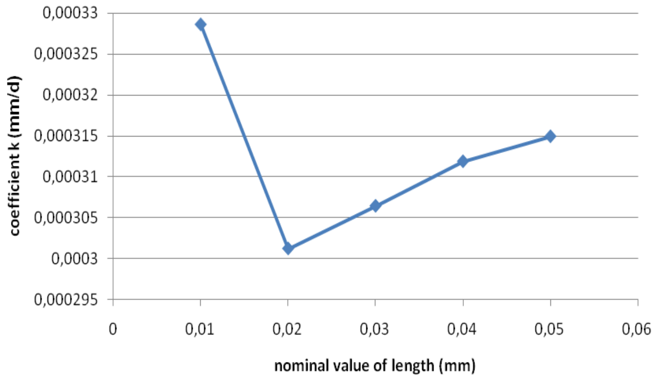

Figure 3. Average values of coefficient (k).

Two operators determined the coefficient (k). Each of them determined five values of the coefficient for 0.01 mm, five for 0.02 mm and five for 0.05 mm, giving a total of 50 values (for both operators). The ambient temperature was 20.6° C and relative humidity RH = 42.1%.

3. EXPERIMENTAL

Average values of coefficient (k) for appropriate measured lengths of objective-micrometer are in Figure 3. Linearity error is significant at the lowest nominal length l = 0.01 mm. It can be seen in Figure 4 that the value of the coefficient (k) and its variability decreases with the growing of the nominal length. The average of the coefficients is shown in Table 1.

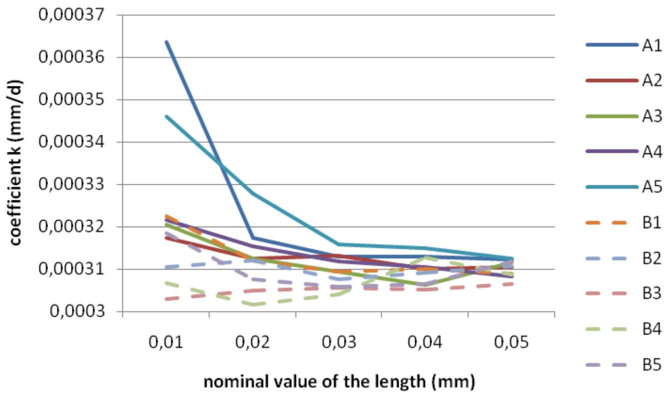

Figure 4. The variability of coefficient (k)

According the unpaired t-test with 95% confidence interval the difference between the average value of the coefficient (k) obtained be appropriateoperators is statistically significant (the two-tailed p= 0.0033). According to two factor ANOVA (analysis of variance) without replication the operator has (p = 0.001145) and the order (used value of l for determination the coefficient) has not (p = 0.0970) statistically significant effect on the value of coefficient (k). This fact results in the impact of the operator on the quality of the calibration and subsequently measured values of the hardness. Despite said difference between operators, their combined results were used for further calculations (row A + B Table 1).

Table 1. Average, minimal and maximal values, standard deviation (SD), outliers and distribution of determined values of the coefficient (k) for particular operators

Operator	average	SD	outliers	Distribution (p value)	max	min
A	0.0003171	0.0000125	3	0.0121 (1)	0.0003636	0.0003063
B	0.0003090	0.0000046	1	0.3988 (2)	0.0003226	0.0003017
A + B	0.0003130	0.0000102	3	0.0012 (3)	0.0003636	0.0003017

(1) The best fit 3-parameter log normal distribution
(2) The best fit normal distribution
(3) The best fit 3-parameter gamma distribution

Table 2. Average, maximum and minimum value, standard deviation SD and p value of an Anderson-Darling test in scale divisions (d) and calculated micro-hardness

	d 195	d 519	average		max		min	
			HV195	HV519	HV195	HV519	HV198	HV519
aver	69.48	42.79	196.64	518.33	145.69	384.03	211.70	558.04
SD	2.197	1.302	12.460	31.580	9.231	23.397	13.414	33.999
max	73.5	45.0	224.02	577.03	165.97	427.52	241.18	621.23
min	65.0	40.5	175.20	467.39	129.80	346.29	188.62	503.20
Normality(p value)	0.4218	0.1998	0.4839	0.1957	0.4839	0.1957	0.4839	0.1957

Results of ten calibrations performed between VI/13 and IV/14 before micro-hardness measurement were used as input values. For each calibration 5 indentations were measured according to [2] and Figure 1. Two CRM (certified reference materials) in the form of the hardness reference block were used as standards for the calibration. The "soft" one has specified hardness $H_c = 195$ HV0.05 and standard uncertainty $u_{CRM} = 4.0$ HV0.05 and the "hard" one has $H_c = 519$ HV0.05 and $u_{CRM} = 6.75$ HV0.05). Two files (for both CRM) of 50 values of lengths of diagonal in scale divisions (d) were the input forcalculations.

Table 2 shows the average, maximum and minimum value, standard deviation SD, and p value of an Anderson-Darling test for normality of input values in scale divisions (d) of the drum and calculated hardness for both CRM.Because all p-values overlap 0.07 it can be assumed that all files have a normal distribution. The outliers do not occur – the process is under statistic control.

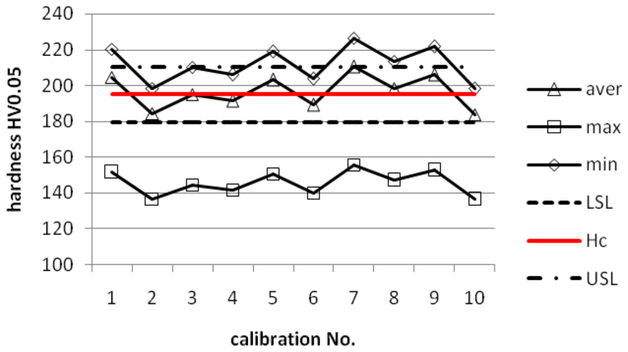

Figure 5. Hardness of "soft" CRM

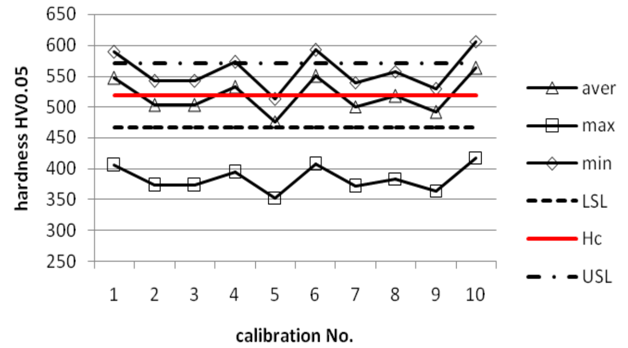

Figure 6. Hardness of "hard" CRM

Figure 5 shows the average values of the hardness of "soft" CRM and Figure 6 of "hard" CRM. Control limits USL and LSL in Figures 5 and 6 match withmaximal permissible error E_{rel} (10% of specified hardness of the used reference block H_c) [2].

Taking into account the average value of coefficient (k), all valuesof the micro-hardness are within control limits. If the minimum value of (k) is used, almost half of values of the micro-hardness lie out of control limits. All hardness values are out of control limits if the maximum value of (k) was used.

According to two factor ANOVA (analysis of variance) without replication considering minimal, average and maximal value of coefficient (k), the coefficient (k) ($p = 5.81E-25$ for "soft" CRMand $p = 8.18E-24$ for "hard" CRM) and also particular calibration ($p = 6.42E-13$for "soft" CRM and $p = 6.42E-13$ for "hard" CRM) have statistically significant influence on the values of the micro-hardness.

4. MONTE CARLO METHOD

The Monte Carlo method or probability simulation is a means of statistical evaluation of a mathematical functions using random samples. It is a probabilistic analysis used to understand the impact of risk and uncertainty in forecasting models [3,4]. When you have a range of values, as a result, you are beginning to understand the risk, variability and uncertainty in the model. The key feature of a Monte Carlo simulation is that it can tell you – based on how you create the ranges of estimates – how likely the resulting outcomes are. In a Monte Carlo simulation, a random value is selected for each of the tasks, based on the range of estimates. The model is calculated based on this random value. The result of the model is recorded, and the process is repeated. Using the Monte Carlo method usually takes a large number of iterative runs to obtain an accurate read failure probability [5] A typical Monte Carlo simulation calculates the model hundreds or thousands of times, each time using different randomly-selected values. When the simulation is complete, we have a large number of results from the model, each based onrandom input values. These results are used to describe the likelihood, or probability, of reaching various results in the model [6].

Monte Carlo method contains a sequence of steps: definition of the input, modeling, estimation of the probability for the input quantities, setup and run the Monte Carlo simulation, summarizing and expression of the results[7] As input parameters for the analysis using Monte Carlo method were used coefficient (k) in the range between maximum and minimum values, (Table 1, row A + B), scale division (d) of the drum in the range between maximum and minimum value (Table 2, columns d195 and d519), and the test load 0.49035 N. In Monte Carlo analysis, one of two sampling schemes are generally used: simple random sampling or Latin Hypercube sampling [3]. Triangular distribution of input values was considered for all inputs in order to simplification. The output is the proportion of values of the hardness out of the tolerance specified for the calibration in the standard [2] (USL and LSL in Figures 5 and 6). Software Quantum XL was used for calculation. The difference between the results of 1000 and 10000 applied simulations, as shown in Table 3, is not large. The input values (k) and (d) change throughout all range in the first column (D-K). Number of micro-hardness values out of the tolerance is high. The value of the coefficient (k) changed and the coefficient (d) remained constant in the second column (K) and value of the coefficient (d) changed and the coefficient (k) remained constant in the third column (D). The graphical outputs for "soft" CRM and 10000 simulations are in Figures 7-9. It is evident that over the considered range the coefficient (k) effects outlier values of the micro-hardness in calibration greater than the coefficient (d).

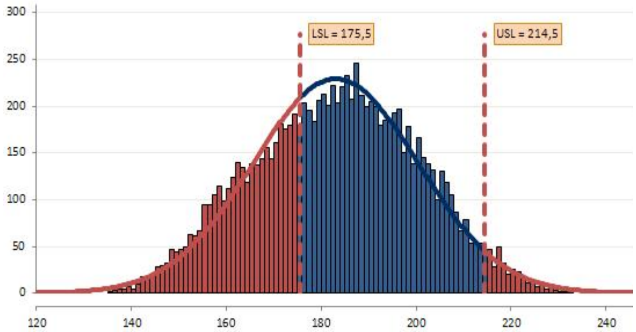

Figure 7. Monte Carlo, output of 10000 simulations, "soft" CRM, the input values (k) and (d) change throughout all range

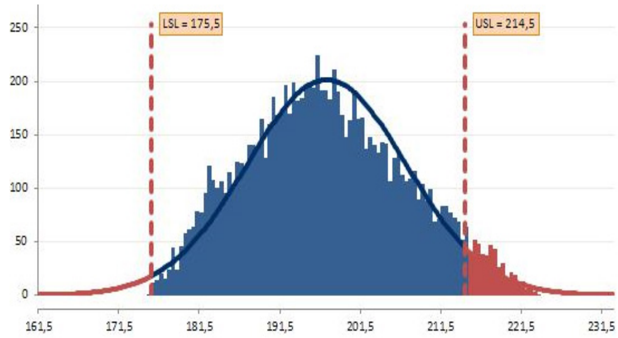

Figure 8. Monte Carlo, output of 10000 simulations, "soft" CRM, the input values (k) are constant and (d) change throughout all range

5. DISCUSSION

In practice, the tables made by operators of the tester in the past are often used to determine the micro-hardness. With their help can be determined the micro-hardness pursuant to the scale interval (d) and test load (F). Their users assume the stability of coefficient (k). On the basis of the presented high variability of the coefficient (k) changes in its value will occur during a single calibration. Thus, each of the five indentations may have a different value of the coefficient (k).

Continuous measurement of the coefficient (k) during the calibration (before each indentation) is a time consuming and difficult pursuable.

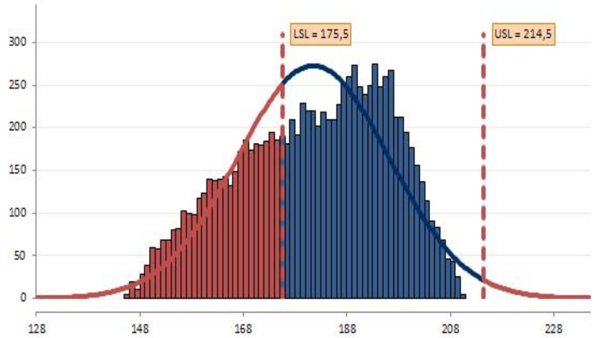

Figure 9. Monte Carlo, output of 10000 simulations, "soft" CRM, the input values (k) change throughout all range and (d) are constant

Realizable compromise would be to determine the coefficient (k) before and after each calibration (to determine its potential instability) and evaluate trends observed over several calibrations (for example by control charts). The influence of the operator on the value of the coefficient (k) must also be remembered.

Table 3. Monte Carlo, proportion of micro-hardness values out of tolerance limits (%)

	D-K	K	D
	1000 simulations		
195 HV0.05	39.1	34.6	5.6
519 HV0.05	47.0	44.7	3.6
	10000 simulations		
195 HV0.05	36.8	35.2	5.5
519 HV0.05	44.8	44.4	3.5

Monte Carlo simulation should be repeated to check for stability and repeatability [3]. The practical use of Monte Carlo simulations is able to resolve the complex measurement problems in the metrology area[6].

6. CONCLUSIONS

- In determining the value of the coefficient (k) used to calculate the actual dimensions when measuring micro-hardness indentation was observed substantial variability.
- This variability has a statistically significant effect on values of the micro-hardness.
- The variability of the coefficient (k) increases with decrease of the nominal length of objective-micrometer used to calculate the coefficient (k).
- Monte Carlo simulations showed that the scattering coefficient (k) has a significant impact on non-conformity with calibration.

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