QUALITY CONTROL OF MICRO VICKERS HARDNESS STANDARD DEVICE BASED ON TOP-DOWN METHOD

Wei Shi¹, Yang Li¹, Dongmei Ren¹, Pan Liu², and Zhongyu Wang³

¹Changcheng Institute of Metrology and Measurement, Beijing, China
²Luoyang Ship Material Research Institute, Luoyang, China
³Beihang University, Beijing, China

swlltm@126.com

Abstract: A new idea of quality control for the repeatability and stability of hardness standard device is proposed. Based on top-down method, this paper tries to apply the grey system theory of non-statistical principle to the standard device repeatability evaluation in hardness testing field. The micro-hardness standard device is evaluated as an example, and the result is compared with that of traditional evaluation methods. This paper evaluates the stability by the method of control charts, and provides evaluation example. We hope that this work will lead to more and better results in the researches of the method for the quality control of laboratory equipment.

1. Introduction
Repeatability and stability are important factors for evaluating the quality of a certain instrument, and they will directly influence the accuracy of the testing result. Therefore, accurate, effective evaluation and control of them are always the particular concerns for measurement inspector. Take micro-hardness testing for example, in ISO 6507-1 <Metallic materials — Vickers hardness test>, there is clear regulations for repeatability and stability of hardness tester.

According to ISO 21748¹, Repeatability is defined as precision under repeatability condition. In the repeatability evaluation of the measurement standard, the consistency among the results are generally expressed by dispersive quantitative of the testing results, that is testing standard deviation of single testing result, and generally regarded as one of the uncertainty quantities of the testing results. Due to the specific characteristics of hardness testing, indentation has no strict repeatability. Therefore, uncertainty evaluation based on classical statistical methods has certain limitations on uncertainty evaluation lead by hardness testing repeatability. This article will try to evaluate uncertainty based on non-statistical principle, mainly applying Grey System Theory.

Stability of metrology standard refers to its ability of keeping metrological characteristics constant with time going on. Therefore, stability of metrology standard is related to time duration considered. This paper takes micro-hardness standard device in laboratory for example, trying to evaluate stability with control charts (also called Shewhart Control Charts), giving evaluation method, and mastering its statistical control state. This also provides reference for quality control of other standard device and testing instrument in the laboratory.

2. Repeatability evaluation of micro-hardness standard device

2.1. Test data
The results of 9 repeatability tests of HV1 are 748.8, 747.1, 748.8, 747.1, 745.4, 750.5, 745.4, 750.5 and 747.1. The results of 7 repeatability tests of a HV0.2 are 447.8, 449.6, 444.5, 446.3, 447.2, 445.7 and 443.9. And the results of 5 repeatability tests of a HV0.05 are 182.3, 184.6, 183.7, 182.3 and 183.9.

2.2. Classical evaluation method
Generally, the repeatability evaluation of the measurement standard depends on the ISO/IEC Guide 98-3 < Guide to the expression of uncertainty in measurement (GUM), which uses the bottom-up analysis logic to focus on the repeatability of measurement results. The repeatability is evaluated mainly depending on Bessel formula,

\[ s_r = \sqrt{\frac{\sum_{i=1}^{m} (x_i - \bar{x})^2}{m-1}}, \]

and it is calculated by \( s_r = \frac{w}{d_{r \sqrt{n}}} \) using the extreme method when there is less test data. The test data shown above are evaluated using the two methods respectively, and the results are shown in Table 1.

### 2.3. Repeatability evaluation based on non-statistical principle

As evaluation based on statistical principle is more suitable for large sample testing, the small sample testing problem with only 5 times hardness tests made still has certain limitations.

In recent years, with evaluation methods become richer day by day, Grey System Method, Fuzzy Set Method, Information Entropy Method, and Bayesian Method etc, which based on non-statistical principle, have appeared one after another. This makes the uncertainty evaluation problem of small sample data or original data which is difficult to determine its distribution laws be effectively solved. It is a favorable complement to the evaluation of statistical analytical method, therefore, it is more and more widely noticed with interest. This article will focus on evaluating Grey Theory.

#### 2.3.1. Principle of grey evaluation

In 1980s, Julong Deng proposed a Grey System Theory which researched small sample uncertainty problems. This theory mainly aimed at Grey System forecasting unknown information by known information of the development system. The biggest characteristic is that it aims at small sample data, and achieves whitening transformation of the system by data accumulation, thus makes uncertainty evaluation gradually clear. Jianmin Zhu and Zhongyu Wang et al have conducted in-depth research on it, and now successfully applied it to the areas such as engineering control.

#### 2.3.2. Definition of grey error

When a measurement system is regarded as a grey system, standard quantity will be regarded as a white quantity. The testing result with measurement uncertainty can be regarded as grey quantity in a certain range, and the measurement error is called grey error. For micro-hardness testing, grey error can be defined as formula \( \bigotimes (\Delta H_{MV}) = \bigotimes (H_{MV}) - \bigotimes (H_{MV0}) \), where, \( \bigotimes \) is grey quantity, \( \Delta H_{MV}(k) \) is micro-hardness error, \( H_{MV} \) is micro-hardness measurement result, \( H_{MV0} \) is ideal truth-value, \( \bigotimes \) is relevant whitened value.

#### 2.3.3. Evaluation example

According to the grey evaluation principle, the uncertainty of test result is calculated by the formula \( \sigma = \frac{c [ S_m - m H_{MV} ]}{n} \), where, \( S_m \) is the accumulative sum of \( m \) measurements which less than arithmetic mean value, \( c \) is the grey coefficient, usually \( c = 2.5 \). Taking the 9 repeatability data as an example, the uncertainty of test result is got: \( \sigma = \frac{2.5 \times [732.1 - 5 \times 747.86]}{9} = 2.00HV1 \), other calculation results are shown in Table 1.

### 2.4. Comparison of three evaluation methods

Table 2 lists the comparison of calculation results between this method and traditional method.

| Evaluation Method | Standard Deviation(9) | Relevant Standard Deviation(9) | Standard Deviation(7) | Relevant Standard Deviation(7) | Standard Deviation(5) | Relevant Standard Deviation(5) |
|-------------------|-----------------------|-------------------------------|-----------------------|-------------------------------|-----------------------|-------------------------------|
| Bessel Method     | 1.92                   | 0.26%                         | 1.92                  | 0.44%                         | 1.92                  | 0.56%                         |
| Extreme Method    | 1.72                   | 0.23%                         | 2.11                  | 0.43%                         | 2.11                  | 0.54%                         |
| Grey System Method| 2.00                   | 0.27%                         | 1.90                  | 0.43%                         | 1.90                  | 0.58%                         |

It can be seen from Table 1 that the test results based on non-statistical principle is coincident with the test results based on traditional evaluation method. Therefore, the grey evaluation can be a complementary to traditional evaluation. When the sample quantity is very small, the grey evaluation method of non-statistical principle is feasible to estimate repeatability and uncertainty in various hardness testing.

### 3. Stability evaluation of micro-hardness standard device

In quality assurance scheme activity in laboratory, it is very important to control the quality and stability of the sample. Stable indication is the basis of making accurate quantity transfer. This paper use control charts method, taking micro-hardness block verification device in laboratory for example, monitor and evaluate the high value stability testing data in a certain period. Control charts are mainly including I chart and MR chart, this time superposition in a chart is applied to improve detection force of horizontal little drift.
3.1. Pre-treatment of testing result

According to stability test data, in order to regulate standardization and accuracy of the control charts, and avoid influence of standard block and standard value change on control charts and parameter for follow-up monitoring, the normalization pre-treatment of the testing result is made first, so the relevant deviation is obtained as the testing results after pre-treatment, as shown in Table 2. After then, the pre-treatment test data with no outliers is further obtained through the selection of suspicious and abnormal data.

3.2. Normality and Independence Examination

According to pre-treatment data and sequential i, calculate index weight moving average (EWMA), the exponential weighting factor set to 0.3 and moving range successively (MR), and according to Bessel formula and moving range method to calculate precision standard deviation $S_{Bessel}$ and $S_{EWMA}$, and calculate standard quantity $z_i$ of $I_i$. Applying independence and resolution of Anderson-Darling(A-D) statistical inspection data, check whether normal distribution model can be built. Apply NORMDIST formula from EXCEL software, or check the cumulative probability table of standard normal quantity $z$, convert $\alpha_i$ standard normal cumulative probability $p_i$. After calculation, the value of $A_2^*$ is 0.48, $A_2^*$ is 0.50. $A_{MR}^*$ calculated by MR method is 0.95, $A_{MR}^*$ is 0.98. $A_2^*$, $A_2^*$, $A_{MR}^*$, $A_{MR}^*$ are all less than critical value 1.0. Assume of data normality under condition of 99% confidence level is acceptable, that is using standard deviation estimated value to build control chart is acceptable. Relevant calculation data is shown in XXII World Congress of the International Measurement Confederation (IMEKO 2018) and E2554[2].

![Table 2](https://www.imeko2018.org/XXII/Table2.png)

The symbols used in 2 to 3.3 are defined in ASTM D6299[3] and E2554[3].

3.3. Build of control chart

3.3.1. I chart. In order to confirm position of $I$ chart and control limit, calculate horizontal center line $\bar{I}$, upper control limit (UCL), lower control limit (LCL), upper warning line (UWL) and lower warning line (LWL) separately. In order to monitor data change more strictly, take the smaller one between standard error $S_{Bessel}$ and $S_{MR}$. If the change of measurement system is only influenced by random error, about 99.7% of the normal distribution test data will be expected to fall in the control limit, and 95% of the normal distribution test data will be expected to fall in the warning limit.

After calculation, $\bar{I}$ is -0.0018, UCL is 0.0108, LCL is -0.0144, UWL is 0.0066, LWL is -0.0102. Add the control parameters such as control limit and center line etc into chart to form I chart, shown is Figure 1.
3.3.2. EWMA superposition. Superpose EWMA trend line on I chart. The EWMA superposed on I chart is the weighted mean of every EWMA’s present result and previous result. Weight will exponential decline with reading increase. Compared with accuracy of measurement system, the shift of average is much smaller. In general condition, EWMA superposed on I chart will improve the sensitivity of average value testing. Series calculated result of EWMA value is shown in Table 2.

After calculation, the upper control limit \( UCL_\lambda \) of EWMA is 0.0035, lower control limit \( LCL_\lambda \) is -0.0071. Superpose relevant data of EWMA on I chart to form the final I chart with EWMA overlay as shown Figure 1. It is shown that the system stability is controlled well by monitoring using the I chart with EWMA overlay in this example.

4. Conclusion
A new method of quality control for the repeatability and stability of micro-hardness standard device is proposed. This article tries to apply the grey system theory of non statistical principle to the repeatability evaluation of micro-hardness. Then it evaluates the stability by control charts method and provides evaluation example. It can be concluded as follows:

1. The repeatability of micro-hardness standard device evaluated by grey evaluation principle is close to that evaluated by classical evaluation method.
2. When the sample quantity is small, it is an effective choice to apply grey evaluation method based on non statistical principle to make various uncertainty evaluations.
3. The evaluation and monitor methods for the stability assessment by control charts method are given by example.
4. The influences of a certain hardness block and magnitude absolute value on control chart (relevant reference line and control limit) are eliminated using the magnitude normalization method, which makes this control chart still have feasibility for follow-up quality process monitoring of standard device and testing instrument after changing to hardness standard substance with same specification magnitude type.
5. The repeatability and stability of hardness standard device are evaluated using the top-down method. A new idea for the quality control of laboratory instruments is proposed, researches will be further conducted in the future.

5. References
[1] ISO 21748-2010, Guidance for the use of repeatability, reproducibility and trueness estimates in measurement uncertainty estimation.
[2] Julong Deng, 1982, Grey Control System[J].Journal of central China Institute of Technology (Journal of Huazhong University of Science and Technology ), 10(3):9-18.
[3] Jianmin Zhu, Zhongyu Wang, Hongzan Bin, A grey evaluation on model of measurement uncertainty[J]. The Journal of Grey System, 2000, 12(3):207-214.
[4] ASTM D6299-17a, 2017, Standard Practice for Applying Statistical Quality Assurance and Control Charting Techniques to Evaluate Analytical Measurement SystemPerformance1.
[5] ASTM-E2554-13, 2013, Standard Practice for Estimating and Monitoring the Uncertainty of Test Results of a Test Method Using Control Chart Techniques.