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The Impact of Long-Term Standard Drift on Metrological Traceability

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***Abstract* – The measurement result by a standard may become unreliable without regular calibration, which may disrupt the chain of metrological traceability. Different chains of metrological traceability led to different measurement uncertainties. The readings of any standard change between calibrations due to its drift. The standard drift affects metrological traceability at all levels of its hierarchy. Taking into account the drift of the standard in practice may include the following elements: determining the appropriate component of the total measurement uncertainty; establishing the frequency of calibration of the standard; using correction during calibration; documenting metrological traceability. A special procedure and software are proposed to simplify the consideration of the influence of time drift of standards on the provision of metrological traceability by calibration laboratories for calibration of standards and measuring instruments.**

I. INTRODUCTION

To ensure metrological traceability, standards must be calibrated regularly [1]. The measurement result by a standard may become unreliable without regular calibration, which may disrupt the chain of metrological traceability. Different metrological traceability chains led to different measurement uncertainties. A generalized model of the metrological traceability chain for different levels of the calibration hierarchy and recommendations for the practical application of the developed model are presented in [2].

The calibration results compare the current values of the standard with higher-level standards. The readings of any standard change between calibrations due to its drift. The drift of the measurement standard or measure used can significantly affect metrological traceability [3], as they are interrelated. The calibration frequency of the standard is determined taking into account the possible drift to compensate for it. Standards with high stability may be calibrated less often than those with significant drift. If the drift is significant and not taken into account, this can lead to incorrect results and violation of traceability. Standard drift must be taken into account in the total measurement uncertainty [4, 5].

The drift of a standard or measure affects the metrological traceability at all levels of its hierarchy [6]. The lower the level of the traceability hierarchy, the greater the drift of the standard and, accordingly, its impact on traceability. Calibration laboratories should take special measures to take into account its impact on the results of calibration of standards and measuring instruments. In this regard, a relevant issue is the development of special algorithms and software to simplify the solution of these tasks by calibration laboratories.

II. METROLOGICAL TIMELINES AND METROLOGICAL TRACEABILITY

Approaches to the impact of time-dependent changes in standard values as part of metrological traceability claims are set out in [7]. A simple metrological time scale illustrating one of several possible internal measurement support systems for a standard in a national metrological institute (NMI) is given in [7]. The time axis, not to scale, shows a sequence of "metrological events" (times t_0, t_1, ..., t_n). The actual duration of a particular event depends on its nature (calibration, monitoring of the standard's characteristics, etc.).

A certain artifact is used to monitor the long-term stability of the standard. For each event, the measurement results and associated uncertainties are recorded. For each event, the measurement result is traceable to a particular standard only at a particular time, but not necessarily at another time. If the calibration laboratory did not perform the required periodic calibrations, the values of the standard at a given time would be unknown and subsequent claims regarding measurement results in traceability statements would be erroneous.

To establish confidence in the integrity of the traceability claim, the calibration laboratory must ensure that the standard has not been damaged or otherwise adversely affected beyond its established control limits. This is done by comparing the results obtained when the standard is used in an identical manner at two different points in time.

The metrological chronology provides a good illustration of the key elements of traceability in NMIs, but for more complex relationships the usefulness of a metrological timeline becomes even more apparent. A laboratory lower in the traceability hierarchy sends its standard for calibration to a higher-level laboratory. Such a laboratory may wish to obtain a traceability statement that links the measurement result of the standard being calibrated to a higher-level standard that existed at the time of calibration using the NMI standard. The presence of a metrological timeline greatly helps to visualize the difference between alternative traceability statements.

The estimation of long-term instability based on time series becomes an integral part of standard calibration. It is necessary to make corrections to the measurement result and establish the corresponding component of the total calibration uncertainty [8]. To estimate the drift of the standard, the deviation between two established corrections at certain calibration points over a certain period of time, the mean value and the standard deviation of the required corrections to compensate for the real drift of the standard or measure are used [9].

III. RECALIBRATION INTERVALS AND DRIFT CORRECTION

Related to the issue of ensuring metrological traceability is the question of the frequency of recalibration of standards. Often, the appropriate recalibration interval is established using an appropriate control chart or by calibration using a reference standard. Traceability links measurements or standards through a hierarchical chain, each link of which is above or below the next [7].

In general, the calculation of the intercalibration interval can be written as follows:

$$\Delta t = \Delta L / S_{Dr} , \qquad (1)$$

where ΔL is permissible deviation range; S_{Dr} is predicted drift rate of the standard under operating conditions.

The change in the measurement value over the *i*-th intercalibration interval is estimated by the expression

$$\Delta X_{Dri} = X_{i+1} - X_i \qquad (2)$$

where X_{i+1} and X_i are the values of the calibrating measure at the moments *i*+1 and *i* of calibration.

For unambiguous standard, the drift rate value of this standard in the *i*-th intercalibration interval are determined based on calibration protocols using the expression:

$$v_{Dri} = \left(\overline{X}_i - X_i\right) / \Delta t_i = \left(\overline{X}_i - X_i\right) / \left(T_{i+1} - T_i\right), \qquad (3)$$

where: X_i is value of the standard when it falls into the *i*-th calibration; $\overline{X_i}$ is actual value of the standard determined during the *i*-th calibration; Δt_i is duration of the *i*-th intercalibration interval; T_i is date of the *i*-th calibration.

The root mean square value of drift rate values of the standard is determined by the expression:

$$\bar{v}_{Dr} = \sqrt{\frac{1}{N(N-1)} \sum_{i=1}^{N} \left(v_{Dri} - \frac{1}{N} \sum_{i=1}^{N} v_{Dri} \right)^2} , \qquad (4)$$

where N is the number of intercalibration intervals that have occurred up to this point.

The correction for the time drift of the reference standard value is equal to

$$\Delta X_{Drt} = \bar{v}_{Dr} \cdot \Delta t , \qquad (5)$$

where $\Delta t = T_N - T_1$ is the time elapsed since the last calibration of the reference standards.

To determine the real standard drift, you need to perform at least three calibrations (minimum), but more is better. The first calibration (T_1) determines the initial value of the standard, the second calibration (T_2) determines a certain change, but does not allow to distinguish random fluctuations from the real drift, the third calibration (T_3) already allows to compare two drift intervals (T_1– T_2 and T_2– T_3). If the drift is similar, this indicates a stable process. With a further increase in calibrations, the influence of random errors decreases, which allows to build a drift trend for a more accurate determination of the drift rate and prediction of the future state of the standard.

The ILAC-G24/OIML D10 [10] identifies and describes available and known methods for estimating calibration intervals. Its purpose is to provide guidance to calibration laboratories on determining calibration intervals within their calibration system. Determining the maximum period that should be allowed between recalibrations of standards and measuring instruments is an important aspect of maintaining the laboratory's ability to produce traceable and reliable measurement results. The ILAC P10:07 [11] describes ILAC’s policy on metrological traceability requirements during testing and calibration.

It is advisable to maintain drift statistics, which involves regularly recording calibration results and analyzing trends over time. These statistics involve collecting, storing, analyzing, and using standard calibration data (calibration date, standard value, measurement uncertainty, calibration conditions).

Data analysis is needed to identify the drift trend: linear regression – to determine the average drift speed; polynomial regression – for non-linear drift; graphical representation – to display changes in the benchmark readings over time, etc. Statistics are used to assess the future state of the standard (predicting drift and determining the optimal time for the next calibration); correcting measurement results (taking drift into account during measurements); reviewing calibration intervals (with stable drift, the intervals can be increased, and with unstable drift, they can be reduced).

IV. PRACTICAL CONSIDERATION OF STANDARD DRIFT

Taking into account the drift of the standard in practice may include the following elements: determining the appropriate component of the total measurement uncertainty; establishing the frequency of calibration of the standard; using correction during calibration; documenting metrological traceability.

The previous results of its calibrations are analyzed to establish the drift speed of the standard. The average drift speed is calculated when a stable change in readings is observed over several calibrations. The resulting drift speed is multiplied by the time interval between calibrations with the addition of the appropriate component to the total measurement uncertainty.

The frequency of calibrations is increased if the standard is prone to significant drift. The optimal time interval, when drift does not yet lead to critical errors, is determined by the results of previous calibrations. If the drift of the standard is predictable (linear or with a known normality), then corrections can be introduced that will allow for time drift without immediately affecting the calibration results.

The determination of time drift, taking into account all calibrations, should be carefully documented, taking into account the following data: dates of calibrations; higher-level standards used; value of drift of the standard and estimate of the corresponding component of measurement uncertainty. Modern laboratory calibration systems can use special software to automate the process of taking into account the time drift of the standard when performing calibrations.

V. PROCEDURE FOR ESTABLISHING METROLOGICAL TRACEABILITY TAKING INTO ACCOUNT STANDARD DRIFT

The following step-by-step instructions are offered for taking into account the standard drift.

1. Analysis of the standard characteristics:

- the type of standard and the parameters to be measured are determined;
- the expected range of drift values is established based on previous calibrations or technical documentation;
- a series of calibrations will be performed to estimate the drift rate if the available data is insufficient.

2. Determination of drift rate:

- the results of previous calibrations are analyzed;
- the change in the standard readings between two consecutive calibrations is determined;
- the average drift rate is calculated using the expression:

$$v_{Dr} = \Delta X_{Dr} / \Delta t. \qquad (6)$$

3. Estimation of uncertainty due to standard drift:

- the time interval between the last calibration and the current moment is set;
- the component of measurement uncertainty caused by standard drift for uniform distribution is calculated using the expression:

$$u_{Dr} = v_{Dr} \Delta t / \sqrt{3}; \qquad (7)$$

- the obtained value of this component is taken into account for calculating the combined standard measurement uncertainty of calibration.

4. Estimation of predicted calibration value:

- the measurement uncertainty component associated with standard drift for the forecast value is calculated using expression (7);
- the value according to the selected one (maximum, average, last) and the number of days since the last calibration for the drift rate are used;
- the forecast value for a certain time is calculated using the expression:

$$X_f = X_N + v_{Dr} \Delta t_{ct}, \qquad (8)$$

where Δt_{ct} is time interval in days since last calibration.

5. Determining the calibration frequency:

- the acceptable level of measurement uncertainty is taken into account;
- the interval between calibrations is set so that the drift does not exceed the permissible limits;
- the maximum calibration interval is calculated using the expression:

$$\Delta t_{\max} = u_{Dr\lim} \sqrt{3} / v_{Dr}, \qquad (9)$$

where $u_{Dr\lim}$ is the maximum permissible value of the measurement uncertainty component associated with standard drift.

The special software "DDrift v.1.0" was developed to implement the presented procedure (Figure 1). The developed software is designed to calculate the standard drift, the standard drift rate, the uncertainty budget component associated with drift, the maximum calibration interval, and the visualization of the obtained results.

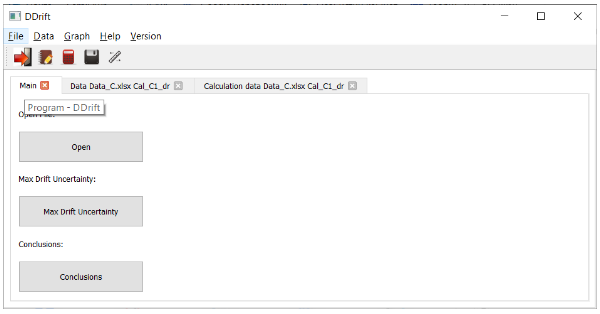
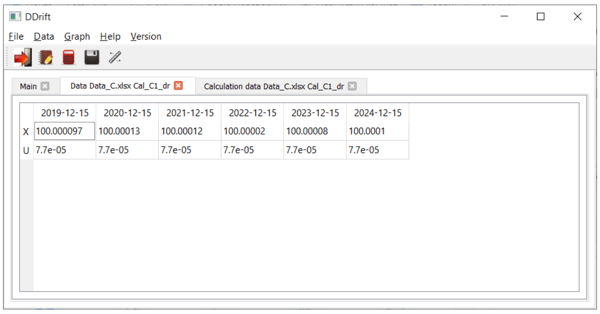


Fig. 1. The screen of "DDrift v.1.0" software.

First, you need to load the data on the calibration of the standard by year. The data is read from the Excel spreadsheet file using the "Open" function. For correct reading, you need to use the appropriate data format in the file: the first column contains the row names, the data in the rows starts from the second column, the first row is the calibration date in the "year-month-day" format (for example, 2024-12-31), the second row is the calibration result, the third row is the calibration uncertainty. When opening the file, you need to select the appropriate sheet of the Excel file with the necessary data (for example, real drift of the capacitance measure of 100 pF from 2019 to 2024). The read data is displayed in a new tab in the software environment (Figure 2).

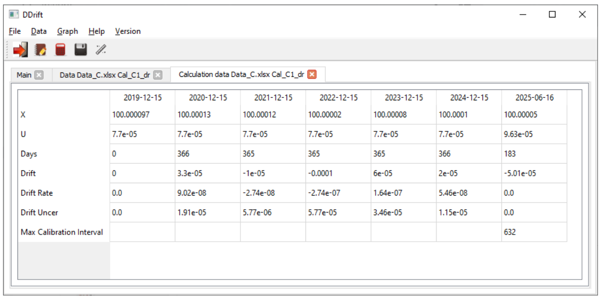


	2019-12-15	2020-12-15	2021-12-15	2022-12-15	2023-12-15	2024-12-15
X	100.000097	100.00013	100.00012	100.00002	100.00008	100.0001
U	7.7e-05	7.7e-05	7.7e-05	7.7e-05	7.7e-05	7.7e-05

Fig. 2. The read data in the software environment.

Next, you need to enter the value of the maximum permissible uncertainty associated with the standard drift and select the value of the drift rate (maximum, average or last) that will be used to calculate the maximum calibration interval and the predicted calibration result.

The calculation of the required data is carried out by clicking the "Calculation" button on the main tab of the program using expressions (6)-(9). The calculated values are displayed in a new tab together with the primary data (Figure 3) for allowed uncertainty of 0.0001 and maximum rate. The predicted calibration value of the capacitance measure with an expected drift of 0.00005 pF as of 2025.06.16 will be 100.00005 pF with an uncertainty of 0.000096 pF. According to the obtained data, the maximum calibration interval of the measure will be 632 days.



	2019-12-15	2020-12-15	2021-12-15	2022-12-15	2023-12-15	2024-12-15	2025-06-16
X	100.000097	100.00013	100.00012	100.00002	100.00008	100.0001	100.00005
U	7.7e-05	7.7e-05	7.7e-05	7.7e-05	7.7e-05	7.7e-05	9.63e-05
Days	0	366	365	365	365	366	183
Drift	0	3.3e-05	-1e-05	-0.0001	6e-05	2e-05	-5.01e-05
Drift Rate	0.0	9.02e-08	-2.74e-08	-2.74e-07	1.64e-07	5.46e-08	0.0
Drift Uncer	0.0	1.91e-05	5.77e-06	5.77e-05	3.46e-05	1.15e-05	0.0
Max Calibration Interval							632

Fig. 3. Results of data processing in the software environment.

To graphically display the results (in special graphic file) of previous calibrations and the predicted value, you need to click the "Graphics" button on the main tab of the program and select the degree of the polynomial for approximating the standard drift trend (polynomials of the 1st, 2nd and 3rd orders). Figure 4 shows a graphical representation of the results for a 3rd order polynomial.

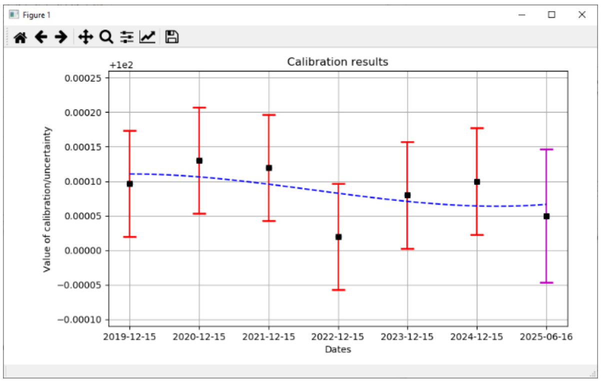


Fig. 4. Graphical representation of data processing results.

It is possible to create a text report with the calculated values, for which you need to click the "Conclusion" button on the main tab of the program.

VI. CONCLUSION

Different chains of metrological traceability have led to different measurement uncertainties. The readings of any standard change between calibrations due to its drift. The standard drift affects metrological traceability at all levels of its hierarchy. The proposed special procedure and software significantly simplify the consideration of the influence of standard time drift on ensuring metrological traceability.

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